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AUTOMOTIVE MANUFACTURING ASSESSMENT SYSTEM
VOLUME IV: ENGINE MANUFACTURING ANALYSIS

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16. Abstract Volume IV - Engine Manufacturing Analysis represents the results of one of four major study areas under the Automotive Manufacturing Assessment System (AMAS) sponsored by the DOT/Transportation Systems Center. AMAS was designed to assist in the evaluation of industry's capability to produce fuel efficient vehicles. An analysis of automotive engine manufacturing was conducted in order to determine the impact of regulatory changes on tooling costs and the production process. The 351W CID V-8 engine at Ford's Windsor No. 1 Plant was the subject of the analysis. A review of plant history and its product is presented along with an analysis of manufacturing operations, including material and production flow, plant layout, machining and assembly processes, tooling, supporting facilities, inspection, service and repair. Four levels of product change intensity showing the impact on manufacturing methods and cost is also presented.

Volume I, Master Product Schedules, portrays, chronologically, current and future product changes and technological advances for each domestic auto (1975-85), light truck (1975-80), and selected import manufacturers (1975-80).

Volume II, Product Schedules of Engine/Driveline Combinations, identifies the available engine, transmission and rear axle combinations for all models of each domestic auto manufacturer for the model years 1975 through 1978.

Volume III, Materials-Weight Analysis, is a detailed compendium of material applications to automotive vehicles and components with emphasis on technological advances and weight reduction potential.

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PREFACE

Volume IV (Engine Manufacturing Analysis) was prepared for the Department of Transportation, Transportation Systems Center (TSC) and presents the results of an analysis of engine manufacturing operations and the effects of regulatory change on production and tooling costs. The work was directed by the Transportation Industry Analysis Branch under the sponsorship of the Energy Programs Division.

The ability of the auto manufacturers to meet the 1979-1985 fuel economy goals will be attributed in a large measure to the degree that they can accommodate product change and still maintain volume production at reasonable cost. Automotive manufacturing operations are complex and the effects of product changes cannot be fully appreciated without some understanding of the manufacturing process itself. The purpose of this analysis was to examine in some detail basic manufacturing operations from start to finish and then, by use of selected examples, determine the effect that different degrees of product change have on machine tooling, assembly, test, service, repair and supporting facilities.

An engine plant was selected for the study because of its high concentration of tooling and capital investment, and the fact that the automotive engine will be undergoing continuous product change if fuel economy and emission goals are to be met.

This study represents one of four major areas investigated under the Automotive Manufacturing Assessment System (AMAS) which was designed to evaluate the capability of the automotive industry to produce fuel efficient cars and light trucks, and to assess the effect such conversions will have on the producers and buying public. The other three study areas are: Master Product Schedules (Volume I), Product Schedules of Engine/Driveline Combinations (Volume II), and Materials/Weight Analysis (Volume III).

This report is divided into four sections plus appendices. Section One (Introduction and Summary) describes the objectives of the investigation and summarize some of the more significant findings. Section Two provides a brief review of the engine plant history and product, while Section Three describes the manufacturing operations in detail. An assessment of the impact on manufacturing methods and cost due to four levels of product change intensity is presented in Section Four.

The analysis could not have been undertaken without the cooperation of the Ford Motor Company, who offered their facilities for the study. The success of the effort is credited to Mr. Richard Shackson, former Director of the Environmental Research Office of Ford and to John Holden of his staff who made all of the arrangements and coordinated the contributions from the Ford Engine Division. The main thrust of the study came under the auspices of the Engine Division and its Windsor Manufacturing facilities. In this regard, special recognition is given to Mr. William E. Fryer, Production Manager, Engine Division; Mr. Phil Gordon, former Plant Manager at Windsor; Mr. Leo Brown, Manufactuirng Manager and present Plant Manager at Windsor; John Kelton, Manager of Downsizing Program; and Peter Corbett of Plant Engineering. John Kelton and Peter Corbett were particularly helpful in arranging access to manufacturing operations, supplying plant layout and manufacturing process data.

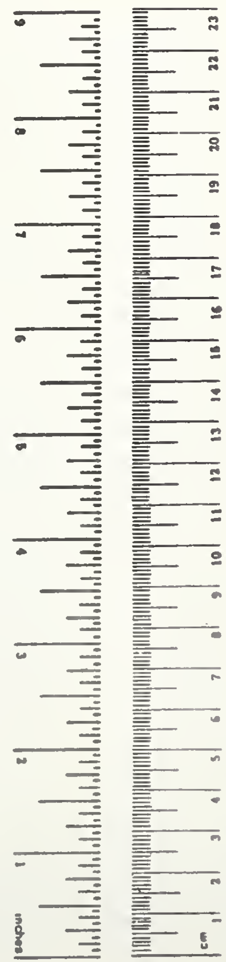
Mr. Gordon Cook, Consultant and retired Ford executive, made helpful contributions towards analysis methodology and identification of manufacturing problem areas.

Corporate-Tech Planning also wishes to acknowledge the guidance and assistance provided by Mr. George E. Byron, Transportation Analysis Branch at TSC, who was the Technical Monitor for this program.

METRIC CONVERSION FACTORS

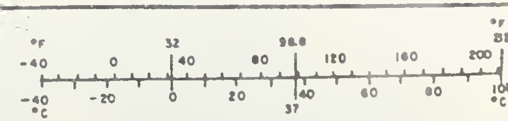
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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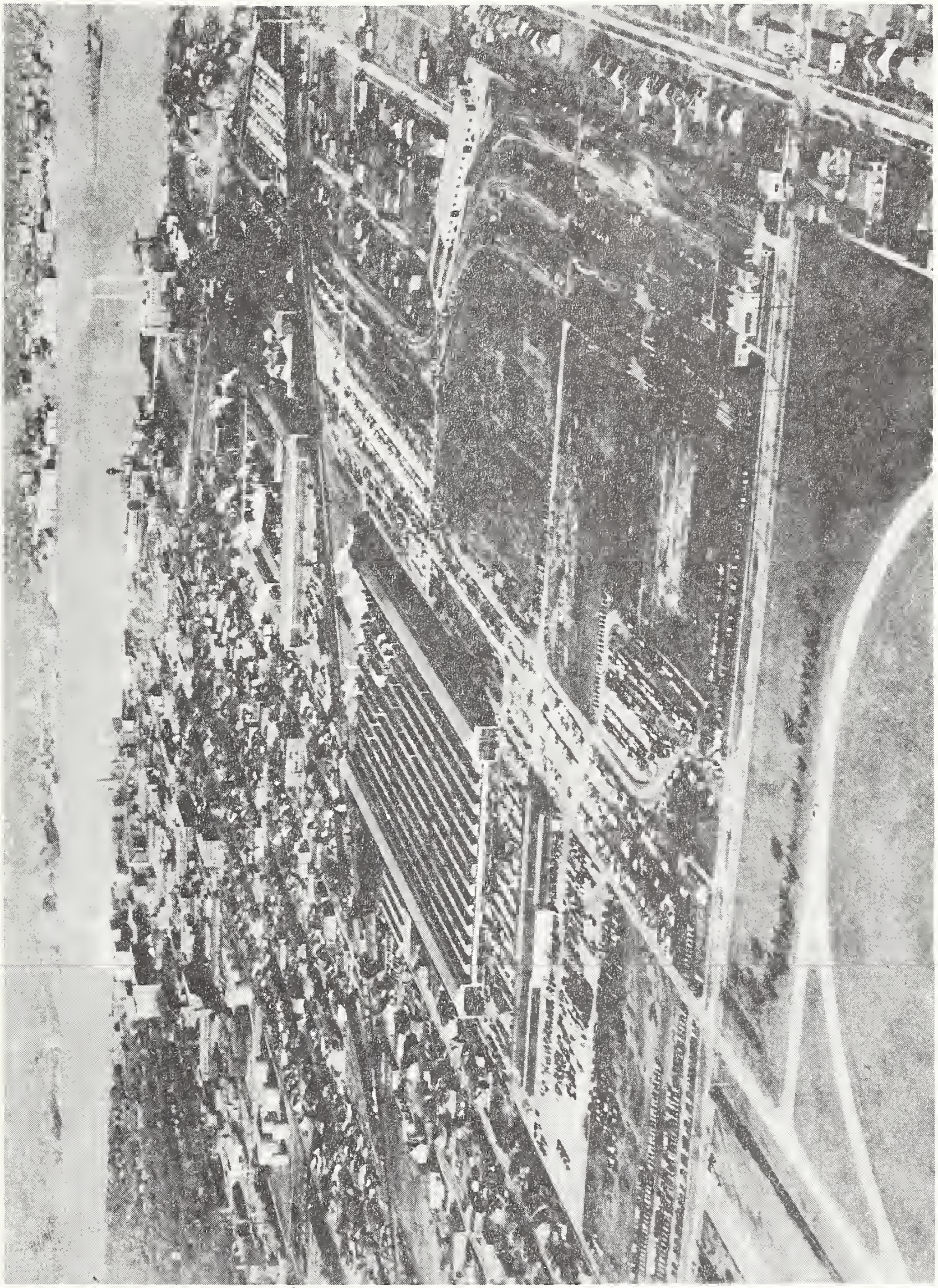

WINDSOR MANUFACTURING PLANTS

1. INTRODUCTION AND SUMMARY

An analysis of automotive engine manufacturing was undertaken in order to gain an insight into the manufacturing process of a modern high volume engine production facility. This in turn would lead to a better understanding of the impact on manufacturing operations due to year-to-year model changes and government regulatory requirement in fuel economy and emissions.

Rather than attempt to study the manufacturing facilities of all the auto makers, it was decided that more meaningful results could be obtained by selecting one manufacturer's plant as an example and concentrating the effort entirely on his operations. The basis of this decision was that all engine plants are similar in principle - they employ the same manufacturing methods and tooling practices, and have comparable production capacities. The results, therefore, would be representative of the industry as a whole particularly with regard to the complexities of engine manufacturing and magnitudes of capital and tooling costs. Moreover, by selecting a single real life plant in the main stream of volume production, a more credible impression of the manufacturing environment could be derived.

The Ford Motor Company offered one of its plants for the purpose of this investigation. The number of Ford Engine Plants in existance (reference Table 1-1) provide a fairly broad spectrum from which to choose. It was decided that the selected plant be an older facility - one which had undergone several facility improvements over its life span. It was also important that its product be of relatively recent vintage, in popular demand, and being produced at near plant capacity levels.

Most of the industry's manufacturing facilities in this country are not really new. Manufacturing operations have been modernized, but the buildings (brick and mortar) themselves are quite old. An all new facility such as Ford's V-6 plant to be built in Ontario would not be representative of industry norm in regard to operational

TABLE 1-1. FORD ENGINE MANUFACTURING FOR NORTH AMERICAN CARS AND TRUCKS

PLANT LOCATION	ENGINE MODEL	ASSEMBLY LINES	VEHICLE USE
Cleveland, Ohio Plant #1	302 CID V-8	2	Cars and Light Trucks
	300 CID L-6	1	Light trucks
Plant #2	351M CID V-8	1	Cars and Light Trucks
	400 CID V-8		
	477, 534 CID V-8	Hand Made	Heavy trucks
Dearborn, Michigan	1.3 & 1.6 liter L-4	1	1981 FWD Cars
Lima, Ohio	2.3 liter L-4	1	Cars
	200 CID L-6	1	Cars
	250 CID L-6		
	370,429,460 CID V-8	1	Trucks
Windsor, Ontario Plant #1	351W CID V-8	1	Cars & Light Trucks
Plant #2	255 CID V-8	1	1980 cars
Windsor, Ontario* (Essex)	3.8 liter V-6	1	1982 Cars
Ford, Germany (Cologne)	171 CID 60° V-6		Small cars
Ford, England (Dagenham)	1.6 liter L-4		FWD Fiesta
Ford, Brazil	2.3 liter L-4		Cars, Courier

* New Plant - Start construction October 1978.

efficiency and plant layout. An all new plant today would obviously reflect the latest manufacturing know-how and technological advances. Older plants in turn, will not attain the same benefits until their present facilities are replaced. Typical industry practice is to assume a 20-year life for the plant and 10-years for capital facilities and non-expendable tooling. Therefore, the auto industry's engine manufacturing resources at any given time is a mixture of a few old plants about ready for replacement, a large number of plants midway in their productive life cycle and a small number of all new facilities that have just recently come on line.

Ford's Windsor Engine complex was selected on the basis it met most of the foregoing criteria. In addition to producing the very popular 351 CID V-8 at near maximum plant capacity, it offered two separate engine plants at the same location from which comparisons could be made. Plant No. 1 was producing the 351-W V-8 on 3 shifts 7 days a week while cutting in manufacturing changes to accommodate new emission control devices and fuel economy improvements. Plant No. 2 was being completely re-tooled to produce a new small light weight 255 CID V-8 for the 1980 model year, after manufacturing large 400 CID V-8's. Consequently both plants offered an opportunity to observe different degrees of change and impact on the manufacturing process, tooling and capital costs.

The analysis attempted to cover as much of the manufacturing process as possible which would provide an overview of the complexities and scale of engine manufacturing. The breadth of the subject matter limited the level of detail in any one area. The broad objectives of the effort were to examine tutorially, the complete engine manufacturing operation from start to finish. This included a review of the plant history and its product, and analysis of the manufacturing operations in such areas as material and production flow, plant layout, the machining process, and the facilities employed in machine tooling and assembly. Finally, an attempt was made to understand the impact on this process brought about by product changes. The impact was analyzed as to the extent of change to manufacturing methods, machine

tool operations, and assembly as well as to cost.

In each of the above broad subject areas, specific examples were also chosen for in-depth analysis. Cylinder block and cylinder head were selected in order to illustrate complex machining operations more clearly. Machine tool production units for boring, drilling, chamfering, reaming and tapping are described along with the supporting activities of inspection, gauging, maintenance, service and repair, and floats. Four classes of product changes in increasing levels of complexity were chosen to illustrate the effect on cost.

The results of the analysis may be summarized as follows:

A. <u>Plant History and Products</u>

Engine Plant No. 1, built originally as a vehicle assembly plant in 1937, was converted to high volume engine production in 1965. Re-tooled for the 351W CID V-8 in 1969. Current capacity is 484,000 units annually.

Engine Plant No. 2, built as a machine shop in 1922, was converted to engine production in 1969 for the 400 CID V-8, and later to 351M CID V-8 in November 1977. Current capacity is 536,000 annually.

B. <u>Manufacturing Operations (Plant No. 1)</u>

Composed of a computerized material and production flow system. Handles incoming orders for all Vehicle Assembly Plants, and controls parts, material storage and re-ordering for over 500 parts and 40 variations of the 351-W engine.

Production process consists of: (a) eleven automated transfer lines for machining cylinder blocks, crank shafts, cam shafts, pistons, connecting rods, connecting rod caps, cylinder heads, intake and exhaust manifolds; (b) seven sub-assembly lines for short block, piston, connecting rod and cap, cylinder head, oil pump, water pump and intake manifold, (c) one final engine assembly line; and (d) 44 test stands for engine hot test.

Production process runs 3 shifts, 7 days a week. Principal machining and assembly area throughput is 65 to 70 units an hour (approximately 55% of theoretical maximum capacity). Line speed is 90 units per hour. Average completed engine rate is about 55.4 to 60 per hour.

90% of completed engines are shipped by rail with balance by truck. 85% are delivered to U.S. operations.

C. Manufacturing Tooling Costs (Approximate)

An automated transfer machine line for an all new 4-cylinder block line costs about $16 million; for an all new V-8 cylinder block line about $20 million; for a 20 station in-line transfer operation (of which 12 stations are active) for drilling, reaming, counter-bore, etc. about $1.2 million.

Approximate cost for an individual machine tool station for boring is $200,000; for drilling and tooling $100,000.

D. Product Change Cost

Four classes of product change have been identified:

(1) PCR - Product Change Request occur year-to-year based on model requirements. Includes cost reduction techniques and responses to regulatory action. Minor to moderate impact; cost of typical individual PCR averages $2 to $3 million.*

(2) Subassembly Change implemented in two to three year intervals. Moderate to high impact, average $25 million range.* Representative examples are aluminum manifold and front cover for weight reduction; case harden valve seats in response to regulatory action.

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*Costs cover plant expenditures only - Engineering of product changes, R&D, and all other support performed outside of the engine plant are not included.

(3) Major Engine Change, such as all new engine and downsized engine, has a very high impact. Requires three to five year lead time, cost range $150 to $250 million.*

(4) All New Plant (Brick and Mortar). $533 million for Ford's new 1.3 million square feet V-6 engine plant, Ontario, Canada. $200 million of the total will go for tooling.

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*Costs cover plant expenditures only - Engineering of product changes, R&D, and all other support performed outside of the engine plant are not included.

2. PLANT HISTORY AND ITS PRODUCT

The Ford Motor Company's manufacturing experience in Canada dates back to 1904, one year after the founding of the Ford Motor Company in the United States. The initial installation consisted of a wagon-works situated on the Detroit River. In 1915 the original building was replaced with a 6-story facility for general manufacturing and automotive vehicle assembly. As Ford expanded its Canadian facilities, additional plants were built away from the river site on the same location where the property is today. The core of the manufacturing facility is built around two main engine plants, referred to as Plants #1 and #2.

2.1 PLANT DESCRIPTION

Engine Plant #1 was built originally in 1937 as a vehicle assembly plant with 571,000 square feet. It later expanded to 695,800 square feet. In 1953 the assembly operations were moved out of the Windsor area and the existing plant was then modified to begin low volume engine production. With the inception of the Canadian/U.S. automotive trade pact in 1965, this plant was reequipped with modern high volume automated facilities to produce the 289 CID engine for the North American market. In 1969 facilities were retooled and the 289 CID was upsized to the present 351 CID configuration (351-W). Present plant capacity for the 351-W engine is approximately 484,000 annually. Construction was recently completed for a 44,000 square foot addition to accommodate new aluminum components manufacture for the 1979 351-W Panther line.

Engine Plant #2 goes back even earlier than Plant #1, having been built originally as a machine shop and stamping plant in 1922. This plant grew to the current size of 794,000 square feet. In 1969 it was converted to engine production for the 400 CID engine. Current capacity for this engine is 536,000 annually. This plant incorporated a new lift and carry automation system to facilitate engine assembly.

Other facilities at the Windsor Manufacturing complex include a power house and a casting plant which are located adjacent to Plant #2. A general layout of the Windsor operation is illustrated in Figure 2-1. The 60-acre test track shown in the illustration is no longer used.

Employment history at Windsor dates back to 1924 when 37 employees were identified at that time in the production of 117 cars. Since then, employment has grown to 4334 hourly and 743 salary. The typical hourly rate is $6.51 to start with an average rate of $7.00 per hour.

2.2 HISTORY OF PRODUCT CHANGES

The chronology of the 351-W engine changes are as follows:

- The original volume produced 289 CID engine that began production in 1965 was derived from the smaller 260 CID which in turn, was derived from a still smaller 223 CID block.

- The 289 later was upsized to the 302 CID and then to its final configuration, the 351-W.

Differences between these various engine size derivatives are primarily deck height, bore and stroke.

From the 400 CID size engine of Plant #2, a smaller size 351-M engine was also derived. The 351-M uses the same block as the 400 CID engine but basically with a shorter stroke (3.5 inches instead of 4.0 inches). Plant #2's production was cut over to the 351-M in November 1977, because of problems in meeting the 1978 fleet fuel economy using the larger 400 CID engine.

Because of the downsizing from 400 CID the 351-M has a thicker wall casting, resulting in a heavier engine than its counterpart in Plant #1 which was upsized originally from the 223 CID block. Consequently, Ford plans to phase out the heavier 351-M engine relying on the 351-W for its present and future production needs.*

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*Ford also produces a 351-C engine at the Cleveland Plant which has the same basic characteristics of Windsor's 351-M.

In summary, Windsor Manufacturing complex has been around for a number of decades and although there has been a shift of products manufactured from vehicles to engines, the brick and mortar structures have remained unchanged despite numerous renovations of plant tooling and facilities. This is typical of present day engine manufacturing practice. Most improvements are made primarily in the area of retooling or by modifying the interior to accommodate new types of manufactured products. Structural changes are performed only when absolutely necessary. At Windsor, brick and mortar were primarily for additions to existing facilities such as the casting plant and aluminum component manufacturing area.

Both engine plants are fully automated, are similar to Ford's other engine plants such as Cleveland, and have roughly equivalent productivity levels.

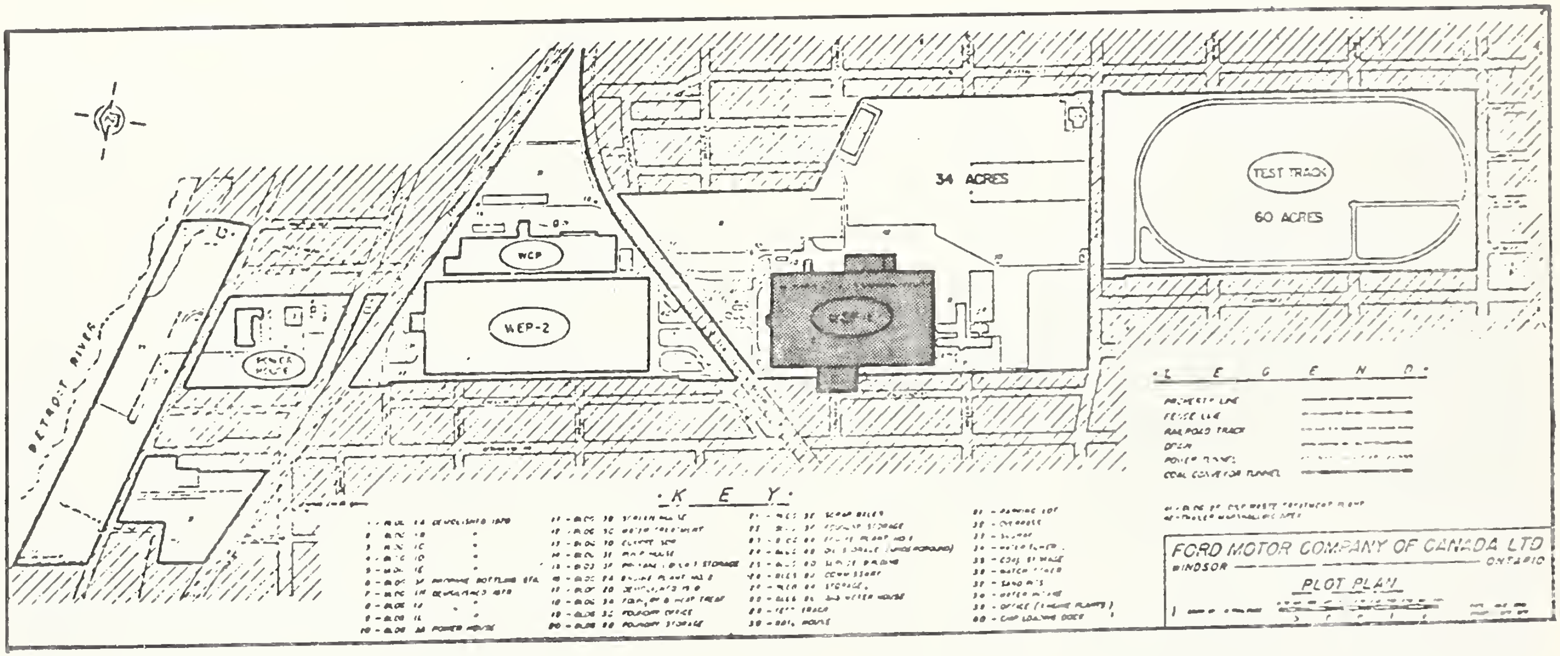


FIGURE 2-1. PLOT PLAN
FORD MOTOR COMPANY OF CANADA
WINDSOR OPERATIONS

3. MANUFACTURING OPERATIONS

The manufacturing operations in a high volume automotive engine plant are complex. A general overview of plant operations, material and production flow is appropriate before discussing in detail specific tooling and assembly operations. This analysis focussed on Windsor Plant #1. Although it is the older of the two engine production facilities the principle manufacturing operations are basically the same for both.

3.1 MATERIAL AND PRODUCTION FLOW

3.1.1 Production Procedures

The primary function of an engine manufacturing facility is to take from outside sources materials in both the semi-finished and finished state, perform the required machining and assembly operations, and dropship a completely tested product for vehicle installation. In essence it is basicallly a machining and assembly operation. An incoming order reporting system is used to coordinate the flow of materials for work-in-process as well as to insure the correct product mix of engine variations. A simplified flow diagram of the manufacturing process is shown in Figure 3-1 with the major manufacturing operations indicated by shading.

A parts and materials inventory storage system accommodates the flow of raw materials, castings, and finished components and assemblies from outside sources. A fairly complex information control system directs and schedules the material to the various manufacturing operations through extensive distribution networks. Depleted materials are replenished based on inventory reordering levels.

3.1.2 Engine Ordering Procedure

Dealer requirements for new vehicles are sent to the Automotive Assembly Division (AAD) which coordinates ordering for all of Ford. The AAD assigns vehicle identification (ID) and computes an ordering schedule called the Weekly Distribution Comparison Report which is sent to each engine manufacturing plant by Monday of each week for

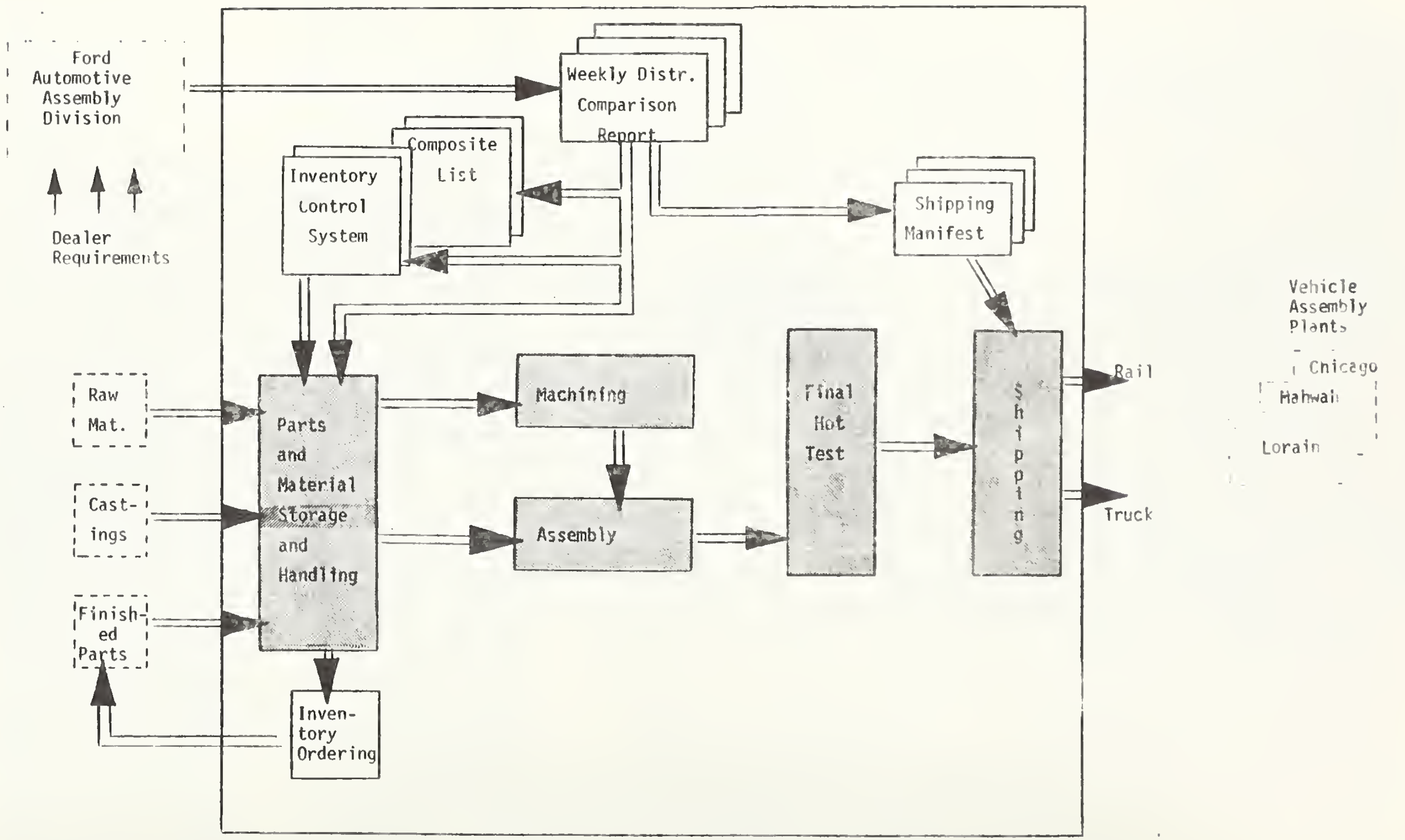


FIGURE 3-1. WINDSOR ENGINE PLANT NO. 1
PRODUCTION FLOW SYSTEM

the forthcoming week's production. This report specifies quantity and code of each engine to be produced and the specific assembly plant destination. From the comparison report a composite list is generated which provides a parts breakdown by quantity and description for each of 40 different engine variations.

3.1.3 Inventory Control

A computerized inventory control system keeps track of over 500 different parts for the 351-W V-8 and its variations. Figures 3-2 and 3-3 are representative samples of the printout of the system from the Windsor plant. Basic elements of the control system are an alphabetical listing of each part by description with part number and name of supplier. Other information includes the purchase order number, and the shipping frequency required to maintain the proper inventory balance. Part and material suppliers are a mixture of other Ford Divisions as well as independent suppliers and vendors in both the United States and Canada. As an example, the cylinder block source is next door from Ford Windsor Casting Plant (Figure 3-2) and is on an 11-day schedule. On the other hand, valve push rods come from Bundy of Canada, (Figure 3-3) with a shipping frequency of every 31 days.

Inventory balance and adequate supply of parts to the manufacturing floor are a continuing problem. Temporary shortages occasionally occur when the plant is operating at maximum capacity with some critical assembly areas often running hand-to-mouth. Delays in shipping, or transportation problems enroute because of weather, contribute to material shortages which, if severe enough, can shut a machining or assembly operation down. A proper mix of inventory balance and shipping frequency are designed to minimize shortages; however, the Inventory Control System must continually monitor supply and adjust balances if necessary.

3.1.4 Product Variations

The Composite List is used to identify the parts in the inventory control system that are required to build specific engine variations. Figure 3-4 is a recent runoff at Windsor. In this example, 17 engine

PROGRAM RO150W INVENTORY CONTROL SYSTEM DATE / /
PLANT WEP1 SUPPLIER NAME DIRECTORY REL PROG - PAGE 14

SUPPLIER NAME	SUPLR CODE	PART NUMBER PREFIX	PART NUMBER BASE	PART NUMBER SUFFIX	PART DESCRIPTION	PART ANALYST	PURCHASE ORDER	SUPL %	SHIP FREQ.
		D7UE	9510	ZD	CARBURETOR	16	9 11679	1.000	31
		D74E	9510	DA	CARB	16	9 11679	1.000	11
		D8UE	9510	DA	CARB	04	9 11679	1.000	31
		D8UE	9510	GA	CARB	04	9 11679	1.000	21
		D8UE	9510	HA	CARB	04	9 11679	1.000	31
		D8UE	9510	KA	CARB	04	9 11679	1.000	31
		D8UE	9510	MA	CARB	04	9 11679	1.000	21
		D8UE	9510	SA	CARB	04	9 11679	1.000	41
		D8UE	9510	VA	CARB	04	9 11679	1.000	41
		D8WE	9510	DA	CARB	04	9 11679	1.000	11
		D8WE	9510	EA	CARB	04	9 11679	1.000	21
		D8WE	9510	HA	CARBURETOR	04	9 11679	1.000	11
		D8WE	9510	JA	CARBURETOR	04	9 11679	1.000	31
FORD MOTOR CO SA	229A	D7AE	6010	BA	CYL BLK	98	9 17844	1.000	21
		D7JE	6010	DA	CYL BLK	98	9 18125	1.000	21
FORD MOTOR CO SALINE	218A	D2ZF	10884	AA	SENDER TEMP	01	9 10995	1.000	32
FORD MOTOR CO SAND	232A	C8AF	6714	C	FILTER ASSY OIL	03	9 6280	1.000	21
		D2AE	6A666	AA	VALVE C/C VENT REG	16	9 18061	1.000	41
		D2OE	6A666	AA	VALVE C/C VENT REG	16	9 10059	1.000	21
		D7AE	6B890	AA	ELBOW + VALVE	03	9 11956	1.000	31
		D8UE	6C317	AA	CONN CR/CASE VT	03	9 00000	1.000	31
FORD MOTOR CO SHEFD	246A	D7AE	6059	AA	CYL COVER	05	9 12040	1.000	11
		D3OE	6110	AA	PISTON	16	9 10007	1.000	11
		D7DE	6110	AA	PISTON	05	9 11901	1.000	11
		D2AE	9A589	AA	CARB SPACER 2V	16	9 10738	1.000	41
FORD MOTOR CO WCP	249C	D4DA	1126	AA	BRAKE DRUMS MAV/	16	9 10536		11
		D42A	1126	BA	BRAKE DRUMS MUST	16	9 10535		41
		D4AE	6015	AA	BLOCK CYLINDER	02	9 11062	1.000	11
[illegible] Casting Plant		DOOE	6090	C	CYLINDER HEAD	02	9 7138	1.000	44
		D5AE	6090	CA	CYLINDER HEAD	16	9 11274	1.000	11
		D7OE	6090	DA	CYLINDER HEAD	16	9 12029	1.000	10
		D7OE	6090	DC	CYLHD ASSY ROUGH	16	9 13259		11
		D7OE	6090	EA	HEAD CYLINDER	30	9 11842	1.000	41
		D8OE	6090	AB	CYL HD	02	9 18152	1.000	11
		C9OE	6250	A	CAMSHAFT	16	9 11054	1.000	11
		D6OE	6250	CA	CAMSHAFT	02	9 11466	1.000	11
		D2AE	[illegible]	CA	CRANK SHAFT	02	9 [illegible]	1.000	11

FIGURE 3-2. INVENTORY CONTROL SYSTEM

PROGRAM RQ160W
PLANT WEPI

INVENTORY CONTROL SYSTEM
SUPPLIER NAME DIRECTORY REL PROG -

DATE / /
PAGE 5

SUPPLIER NAME	SUPLR CODE	PART NUMBER PREFIX	PART NUMBER BASE	PART NUMBER SUFFIX	PART DESCRIPTION	PART ANALYST	PURCHASE ORDER	SUPL %	SHIP FREQ.
BUNDY OF CANADA LTD	068C	C9OE	6565	C1	PUSH ROD	16	9 8431	.700	21
		D7OE	6565	A1A	ROD VLV PUSH	98	9 00000	.700	21
		D7OE	6565	A1B	ROD VALVE PUSH	03	9 11981	.700	21
		D8OE	6565	A1A	ROD VALVE PUSH	98	9 15318	.500	21
BUNDY OF CANADA LTD	068C	D7OE	6565	A2A	ROD VLV PUSH	98	9 00000	.300	21
		D5AE	6759	BA	TUBE CRANKCASE	16	9 11010	1.000	41
		D5UE	6759	AA	TUBE CRANKCASE	16	9 11115	1.000	41
		D5OE	9B273	AB	TUBE ASSY FUEL	16	9 11113	.500	41
BUNDY TUBING DIV.	068A	D5AE	9820	BA	THERMOSTAT TUBE	16	9 10674	.500	42
		D5OE	9B273	AB	TUBE ASSY FUEL	16	9 11112	.500	41
BURLINGTON DIE CAST	075C	C9OE	6604	C	OIL PUMP BDY	02	9 10474	1.000	21
C A G PRODUCTS	079A	D8AE	6A528	AA	GUIDE VLV RCKR ARM	16	9 18110	.500	42
		D8AE	6A528	AB	GUIDE VRA FULCRUM	98	9 13297	.500	41
CADILLAC RUBBER &	078A	D8AE	12226	AA	HOSE DIST VAC	04	9 13333	1.000	32
		D8AE	9B999	BB	HOSE FUEL VPR RET	04	9 00000	.500	41
		D8AE	9E455	CA	CONN	02	9 18040	.500	41
		D8UE	9E455	FA	CON EMI VAC CTRL	01	9 18035	1.000	41
		D8UE	9E498	BA	CONN EMIS VAC CTRL	04	9 18032	1.000	41
			381335	050W	TUBE VAC 5/32	04	9 13326	1.000	41
			381335	080Y	TUBE VAC	04	9 10823	1.000	41
			381335	090W	HOSE 9 WH	04	9 17786	1.000	41
			381335	120Y	TUBING VACUUM	16	9 12623	1.000	41
			381335	140W	TUBE VACUUM	16	9 11916	1.000	41
			381335	140Y	TUBING	04	9 13423	1.000	41
			381335	150W	TUBING VAC	04	9 17797	1.000	41
			381335	170Y	TUBING VACUUM	16	9 11414	1.000	41
			381335	180W	TUBE VAC	04	9 18019	1.000	41
			381335	210Y	HOSE	16	9 12395	1.000	41
			381335	320R	TUBE VACUUM	16	9 11992	1.000	41
			381336	160B	TUBING VACUUM	16	9 12622	1.000	41
			381337	012A	HOSE	04	9 11131	1.000	41
			381377	043A	HOSE	16	9 11213	1.000	41
CALIFORNIA IND PROD	085A		3-5165	S2	NUT STPD	05	9 17705	1.000	41

FIGURE 3-3. INVENTORY CONTROL SYSTEM

Part No.		Description	JA 3 8 6 BA	JB 3 8 6 BA	JA 3 9 0 BA	JB 3 9 0 BA	JX 3 9 0 01	JK 3 8 5 BA	JK 3 8 8 BA	JK 3 9 2 BA	WL 3 9 7 BA	WK 3 9 6 BA	WL 3 9 8 BA	JE 3 8 9 RA	JE 3 9 1 RA	WL 3 9 4 BA	11 8C 7 0 2 BA	30 8Y 7 0 2 03	77 .2 0C 7 0 3 BA
			Passenger					Econoline									Marine		
					Ford			Calif.											
D0AE	6152A2	PISTON RING	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
D7AE	6159AA	SEGMENT P/RING	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
D7AE	6161AA	EXPANDER P/RING	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
D2JE	6176CA	DECAL FIRING ORD															1		
D2JE	6176DA	DECAL F/ORDER																	1
AD6OE	6200AA	CONN ROD ASY	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
D6OE	6205AA	CONN ROD	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
C9OE	6210A	CONN ROD CAP	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
C9OE	6211A	CONN ROD BEARING	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
C1TE	6212A	NUT CONN ROD	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
C9AE	6214A	CONN ROD BOLT	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
D2JE	6250RA	[illegible]																	
D2JE	6250CA	[illegible]																	
D6OE	6250CA	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
C9TM	6256A	SPROCKET					1												
D2AE	6256A2A	SPROCKET CAMSHAF	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6261A1	BEARING C/S FRT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6262A1	BEARING C/S CTR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6263A1	BEARING C/S REAR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6265C	SPACER C/S SPROC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6266A	PLUG	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6267A1	BEARING CAMS FRO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3OE	6268A	[illegible]																	
Z5TE	6268A	[illegible]																	
C9OE	6269B	PLATE C/SHT THRU	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
C9TM	6269B	PLATE C/THRUST					1												
C2OE	6270A1	BEARING C/S INTE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2OE	6278A	WASHER C/S SPROC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3OE	6287A	C/S OUTER ECCENT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D7AE	6287AA	ECCENTRIC C/SHFT	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
~~AD2AEM~~	~~6303CA~~	CRANK MEG															1	1	
~~AD2JE~~	~~6303?A~~	[illegible] REV																	
D4OE	6303AA	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C4OE	6306A6	SPROCKET CRKSHT	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
Z5TE	6306A	SPROCKET CRKSHT					1												
C3OE	6310A	SLINGER FRT OIL	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
D0AE	6310A	SLINGER FRT OIL															1	1	1
C9OE	6316E1	DAMPER ASY-CRKSH												1	1				
D0OE	6316C1	DAMPER ASY CRKSH	1	1	1	1	1	1	1	1									1
D1JE	6316A1A	DAMPER ASY CRKSH									1	1	1			1			
D2AE	6316A2A	DAMPER ASY CRKSH												1	1	1	1	1	1
ADOAE	6325E	C/S MAIN BRG CAP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ADOAE	6327E	C/S MAIN BRG CAP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DOAE	6329E	BEARING CAP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ADOAE	6330E	C/S MAIN BRG CAP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D1AE	6333AA	BEARING CRANKSHA	4	4	4	4	4	4	4	4	4	4	4	4	4	4			
D7AE	6333AA	BEARING C/SHFT															4	4	4
ADOAE	6334E	C/S MAIN BRG CAP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D1AE	6337AA	BEARING CRKSHT T	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
D1JE	6337AA	BEARING CRKSHT T															1	1	1
C7AP	6375F1	FLYWHEEL ASY	1	1	1	1											1	1	1
C7ZE	6375B	FLYWHEEL ASY						1	1			1	1	1		1			
D6UP	6375AA	FLYWHEEL ASSY																	
D7TE	6375GA	FLYWHEEL ASSY					1												
D7TE	6375GB	FLYWHEEL								1	1				1				
EDC	6378A	WASHER CRKSHT DA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D1TA	6394BA	FLYWHEEL HOUSING																	
EAD	6397A	DOWEL PIN	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D0OE	6500B	TAPPET 351	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
~~D7DE~~	~~6505AS~~	~~VALVE EXH~~																	

D4JE-M-6303-AA
D4JE-6303-AA

USE HP SURPLUS

FIGURE 3-4. COMPOSITE LIST

variations are currently in the production run at that time. These variations are identified by the column headings of the chart, with each engine type having its own identifying code. JA and JB series are basically passenger engines; whereas JK, WL and JE are for trucks and vans. The last three columns illustrate three variations of a marine engine. A major cause for engine variations is due to emission control device differences depending upon whether the vehicle is to satisfy the 49-state Federal Standards or to meet the more stringent requirements of California. Another variation is attributed to intake manifolds for two or four barrel carburetors. Truck engine variations are usually related to engine head sizes and bore clearances. Marine engines retain basically the same geometry as vehicle engines but require special consideration towards corrosion resistance for oil and water pumps, use of brass core plugs and some differences in heads, valves, valve springs, and rocker arms. As an example, the same cam shaft is used interchangeably between the passenger and light truck engines but a different one is required for the marine version. Another marine difference is illustrated by the reverse crank shaft, which permits the marine engine to rotate in the opposite direction from the land version. Engine variations shown are run interchangeably through the manufacturing process; however, they are usually built in runs of 50 for manufacturing and material handling convenience.

3.1.5 Production Records and Shipping

The weekly distribution comparison reports keep track of the finished engine orders. These reports are initiated every Monday of the week but for one reason or another are revised the very next day. Figure 3-5 illustrates a typical comparison report of December 1977. Various orders are identified for shipment to Chicago, Los Angeles, Wayne, and Mahwah assembly plants. These orders are matched against the specific engine code and quantity. Because of continuous changes to the orders based on the change in demand back at the assembly division facilities

12/13/77 ENGINE DIVISION AC250W PAGE 1

WEP=1 **WEEKLY DISTRIBUTION COMPARISON REPORT** RELEASE NO. 371-SR

ENGINE CODE TAG OR PART NUMBER		ASSEMBLY PLANT	*DEC* ACCUM THRU PRIOR MNTH	QUAN CHANGE	*12/12* ACCUM THRU CURR WEEK	QUAN CHANGE	*12/19* ----SHIP WEEK---- --ACCUM--	--NET--	ACCUM THRU 1ST PLN WK	*JAN* ACCUM THRU SHIP MONTH	QUAN CHANGE
=HG	390C9	CHGO									
=		LOSA									
=		LSVL									
	TOTAL PART NUMBER										
	TOTAL										
=HG	384AB	WAYN									
	TOTAL PART NUMBER										
=HG	386AC	MAHW									
=		WAYN									
	TOTAL PART NUMBER										
	TOTAL										
	TOTAL 1977 VERSAILLE										
=HA	3900I	IETD									
	TOTAL PART NUMBER										
=7C	702AA	DIEP									
=		IETD									
	TOTAL PART NUMBER										
=7Y	70233	IETD									
	TOTAL PART NUMBER										
=7C	703AA	DIEP									
=		IETD									
	TOTAL PART NUMBER										
	TOTAL 1977 MARINE										
	TOTAL 1977 MARINE										

Initiated Every Monday

Revised Very Next Day

FIGURE 3-5. WEEKLY DISTRIBUTION COMPARISON REPORT

a running inventory showing the cumulative number of orders as well as the changes is maintained. Weekly and monthly order accumulations are illustrated by the column headings.

The same information control system that handles the incoming orders and identifies the parts against the composite list also controls shipping destinations of the final product. This activity is manifested through the shipping order. Figure 3-6 is an example of invoice for the Ford Motor Company Oakville, Ontario assembly plant. In this example, an order consisting of 16 racks (or total quantity of 64) JE-389-BA engines, for vans, is to be shipped via truck.

Although all incoming materials are brought in by truck 90% of completed engines are shipped by rail with the balance transported by truck.

3.2 PLANT LAYOUT

Although the primary manufacturing functions of the engine plant are machining and assembly, it includes supporting facilities such as stock storage, maintenance, inspection, quality control, receiving and shipping, and general office space for personnel, administration and engineering. A general layout for Plant #1 is shown in Figure 3-7. Machining operations take up most of the manufacturing floor space with the various engine assembly areas a close second. The machining operations are generally arranged to accommodate a sequential build up of engine assembly. As an example, cylinder block machining starts at one end of the building, followed by crank shafts, cam shafts, pistons, cylinder heads, and manifolds. Rough castings flow into the machining operations at one side of the building and exit as machined parts as close to engine assembly operations as practical. Windsor was initially set-up more optimally than today. As engine changes and improvements over the intervening years caused changes in manufacturing methods, layout efficiencies of the basic manufacturing operations were compromised. However, the permanency of complex machining

ENSITE LIMITED
WINDSOR ENGINE PLANT # 1

2950 METCALFE ST.
WINDSOR, ONTARIO, CANADA
N9A 4M4

/ 8 TUE.

INVOICE NO. 81- 207011

DATE ISSUED	PROD	MAV	NON PROD	CHG ON MENT	MISC ASSY	SCRAP	SALVAGE	DIST MATL	MISC	HOW SHIPPED (ROUTE)		EXP.	COLL.	PPD.	PARCEL POST	INSURANCE VALUE
12/20/77	X									TRUCK	T01		X			

TYPE OF SHIPMENT

INITIALS AND CAR NO

GROSS WEIGHT 51584
TARE WEIGHT 16000
NET WEIGHT 35584

LENGTH OF CAR — ORDERED — FURNISHED

CONTAINERS 16 RACKS

SEALS

SOLD TO: FORD MOTOR CO.
OAKVILLE ASSY. PLT.
OAKVILLE, ONT.

ATTENTION: ACCOUNTING DEPT.

SHIP TO (IF OTHER THAN SOLD TO)

ACCOUNT DISTRIBUTION

SHIP. LOC.	RECV. LOC.	RET	BILL	SUPP	CLMS.	PLT.	TXN
51-55	56-60	71	72	73	74	78	79-80
	2311					T	32

DATE TO SHIP	CUSTOMER ORDER OR AUTH. NO.	ISSUED BY		TERMS	F O B	INVOICE REFERENCE
	P 276999					

REQUESTED BY	PHONE	DIST. CODE	STOCK LOCATION	BUILDING CODE	REJECTED MATERIAL	REC. REPORT NO.	REC. REPORT DATE	INSP REPORT NO
M. MULLIN 593	(ES)							

QUANTITY ORDERED	PART NO. - CODE - DESCRIPTION	CHECKER'S NO & SHIPPING INFO	WEIGHT	TRAFFIC CODE	QUANTITY SHIPPED	UNIT PRICE	AMOUNT
	Econoline Truck						
	JE-389-BA ENGINE ASSY.				64		
	A.E.T.C.# 1220030 CODE G-4						
	W-206 RAIL RACK			16			

TOTAL CHARGES

AUTHORIZATION TO RELEASE (SIGNATURE) Robert Murp— BADGE NO 8140 DATE SHIPPED 12-20-77

TRUCK NAME AND NO Laidlaw 4304 CARRIER'S SIGNATURE N. Johnson B/L OR W/B NUMBER

81- 207016

EL 3040 PROD CONT (WEP-1) JUNE 1976

FIGURE 3-6. SHIPPING INVOICE

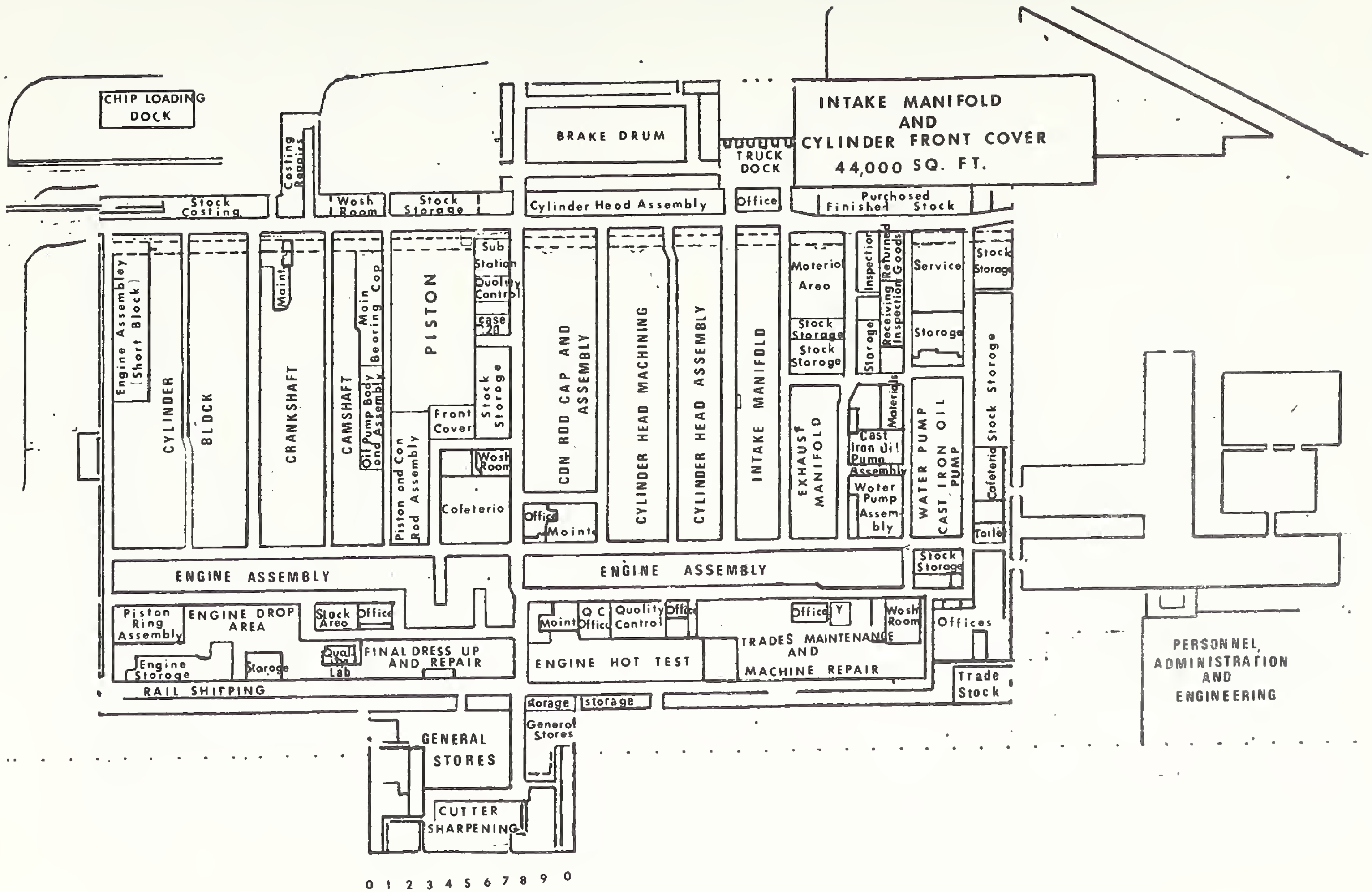


FIGURE 3-7. WINDSOR ENGINE PLANT NO. 1 JULY 1977

operations make them expensive to move and subsequent relocation of these facilities to accommodate more efficient floor space is done sparingly. Hence, much of the plant's layout today is as it was originally constructed in 1965 when it was initially renovated for high volume production.

Referring again to Figure 3-7, incoming materials arrive at one side of the building by both truck and rail. Numerous stock storage areas for the individual components and castings are positioned close to where the machining or assembly takes place. As such, there is no centralized material storage. Semi-finished products such as pistons and connecting rods undergo incoming inspection and grading before they are sent to their final machining. A general area for these operations is on the right hand side of the floor plan. Engine assembly takes place at the bottom of the floor plan doubling back for final engine hot test, dress up and then temporary storage prior to shipping. Finished engines depart either by rail or truck. Each engine plant has its own administrative office facilities for personnel, manufacturing engineering and other functions.

3.2.1 Production Capacity

Production volume at engine Plant #1 demands a three-shift operation. As indicated in Table 3-1, machining operations run seven days a week right around the clock. All of the manufacturing requirements are satisfied by one line for each of the major component machining areas with the exception of cylinder heads and exhaust manifolds, in which case two lines are used. Final engine assembly can be accommodated on a five-and-a-half day week production basis. This is due mainly to the quantity of engine test stands available which permit a throughput that matches the production capacity of component machining and assembly. Throughput for the principal machining and assembly areas is 65 to 70 units per hour which is approximately 55% of theoretical maximum capacity. The line speed, when moving, is about 90 units an hour. However, the average hourly rate for completed engines is about 55.4 to 60 per hour.

TABLE 3-1. PLANT NO. 1
OPERATION AND FACILITIES

LINE TYPE	NO. OF LINES	NO. OF SHIFTS	DAYS/WEEK
MACHINING			
Block	1	3	7
Crankshaft	1	3	7
Cam shaft	1	3	7
Piston	1	3	7
Connecting Rod	1	3	7
Connecting Rod Caps	1	3	7
Cylinder Head	2	3	7
Intake Manifold	1	3	7
Exhaust Manifold	2	3	7
ASSEMBLY			
Short Block	1	3	7
Piston	1	3	7
Connecting Rod and Cap	1	3	7
Cylinder Head	1	3	7
Oil Pump	1	3	7
Water Pump	1	3	7
Intake Manifold	1	3	7
FINAL ENGINE ASSEMBLY	1	3	5½
ENGINE HOT TEST	44 Stands	3	5½

This is typical manufacturing practice and the limitations are not due so much to the duration or capacity of the machines, as it is to a combination of factors such as load imbalance of work-in-process, unscheduled maintenance, labor and learning curve problems.

3.2.2 Production Process

A more graphic representation of product flow through the machining and assembly operations is illustrated in Figure 3-8. As mentioned before, this plant is fully automated. Once the materials and components are on the floor, the manufacturing process requires little human intervention. As an example, after block castings enter the block machining line, they are indexed automatically through each machining and assembly operation by various types of automated conveyors.

A) Engine Block

Engine block machining is the overall focal point of engine manufacturing operations. Block machining is also the most complex, often becoming the bottleneck of the total production process. The engine block proceeds from machining to the short block assembly* as illustrated in the left of the diagram, and then into final engine assembly where other machined components arrive in sequence.

B) Crank and Cam Shafts

Crank shaft machining is adjacent to block machining because of the sequence in short block assembly. Crankshafts are followed by

*Installation of: Crank and cam shafts, main bearings, timing chain and sprocket, cam shaft thrust plate, cam shaft cup plug, front and rear cover dowels.

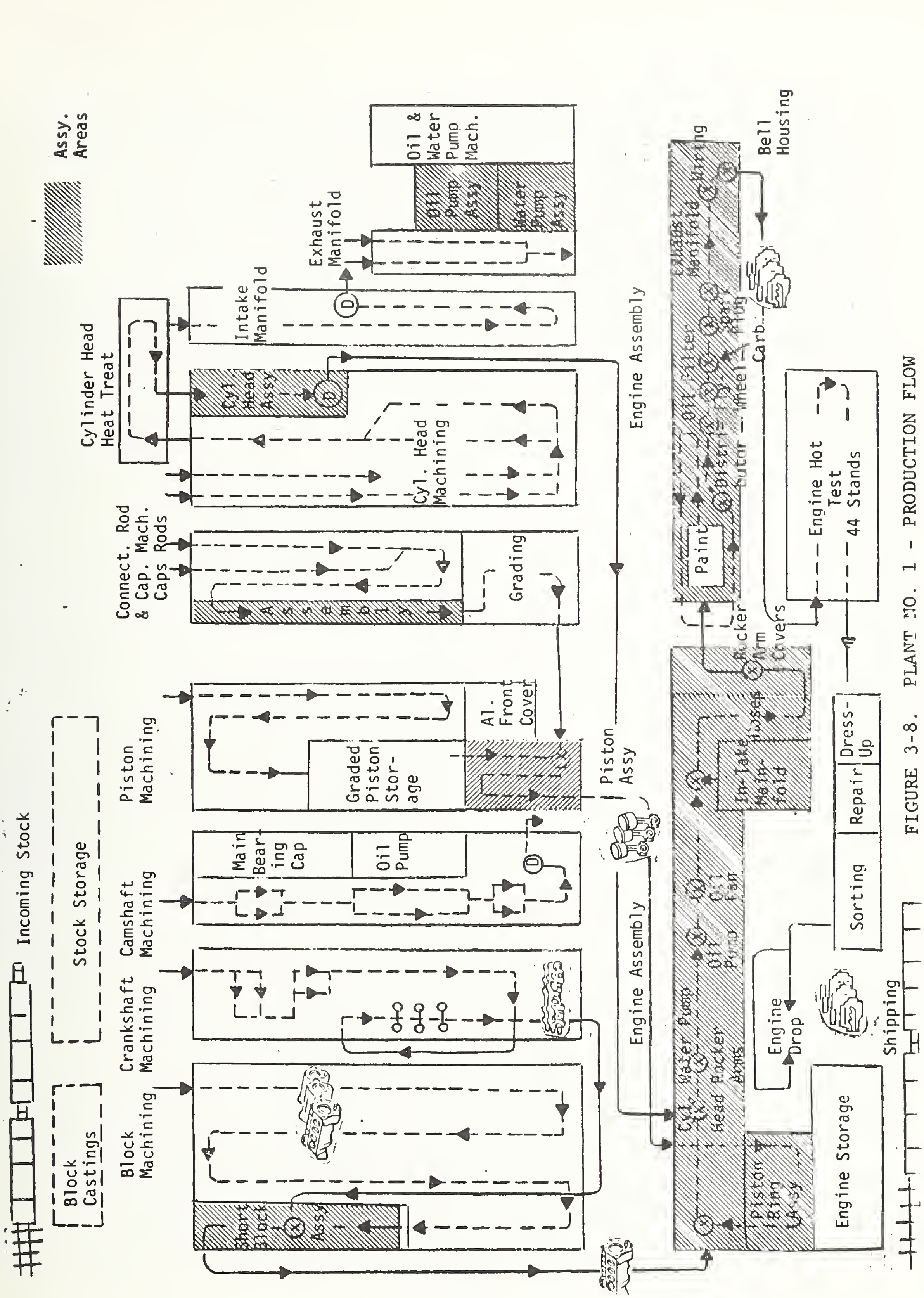


FIGURE 3-8. PLANT NO. 1 - PRODUCTION FLOW

machining of the cam shafts and pistons. The machining operations will double back as many times as necessary in order to fit all sequences into the operation. Parallel machining operations are used wherever single operations are incapable of maintaining throughput. This is illustrated on crank shafts where as many as six parallel operations are needed for crank shaft balancing. In a few instances, some of the finished machine parts such as exhaust manifolds and cam shafts are manually delivered to the assembly operation on pallets in lieu of automated conveyors.

C) <u>Pistons</u>

Pistons are made of 319 aluminum. Machining consists of one rough cut at the foundry and then machine finished at the engine plant with another rough and one fine cut. A thin layer of tin plate is added to serve as a lubricant during engine break in. Most of the pistons come from the Sheffield, Alabama plant via truck. Windsor machines approximately 24,000 per day maintaining an inventory of around 70,000 at any one time. A gravity feed carousel extending to the roof of the plant provides a one-hour automated material supply of pistons to the machining process.

The cylinder block is machined to the same tolerance differences (within .0015") as the pistons with grading performed after cylinder bore honing. Cylinder size differences on each block are then coordinated with piston assembly such that correct numbered sets of pistons reach the block in the final assembly sequence.

Because of machining tolerances, all pistons contain some variations in size. Rather than maintain tighter and more expensive machining tolerances for both pistons and cylinders, the size variations are accepted as is and grouped according to a grade classification. This classification consists of 7 number grades and 3 letter size grades based on tolerance differences of .0025 inch. Grading is accomplished after the pistons have been temperature stabilized for 24 hours at 72^{o}. Each piston size then is numerically coded according to the grade classification.

A single 8 cylinder block engine may consist of four or five different cylinder bore sizes.

D) Connecting Rods and Caps

Connecting rods and caps receive a rough bore finish and then are bolted together for a fine bore finish which insures close crankshaft and wrist pin fits. The parts are then separated and shipped as pairs to the final assembly area. As indicated in Figure 3-8, the rods are assembled first with the pistons, then delivered as a completed subassembly for final block assembly.

E) Cylinder Head

Cylinder heads are machined in pairs in order to sustain the required production throughput for each engine. An extra loop in cylinder head machining was instituted with the advent of non-leaded gasoline. The higher exhaust temperatures from use of non-leaded gas required that all head valve seats be heat treated. This requirement increased the complexity of cylinder head machining by 20% as indicated by the added loop in Figure 3-8. Some of the smaller components require less machining operations such as the oil and water pump. These operations, (performed on the right hand side of the floor plan) consist of milling, drilling, and boring in a two step process, once on each side. These components are assembled in a separate subassembly area with the oil pump being performed in two locations because it is also supplied to Plant #2.

F) Assembly Sequence

The locations of the various assembly areas are dictated by their sequence in the manufacturing operation as identified by the shaded areas on the diagram. It is important to note that a major portion of the engine assembly is actually performed at a subassembly stage. As an example, the head is completely assembled before it is delivered to the main engine assembly as are the piston assemblies, oil pumps/water pumps. After short block, the

major assembly operation is on the engine itself. This operation transverses the complete length of the building and then doubles back for engine hot tests. Most of the manual operations in the plant are performed at engine assembly. Even here, a lot of it has been automated. Cam shafts are inserted by machine at short block assembly. Although most bolts for connecting rods and main bearing caps and other parts are hand started, they are followed up by air wrench. As the engine assembly progresses, it is carried in a special fixture which allows it to be supported in any desired orientation on the lift-and-carry system. Only the major assembly operations are indicated on the flow diagram. Periodically work-in-process is allowed to build up along the assembly line. This insures an even distribution of production flow and smoothing out of discontinuities in the assembly process.

G) Hot Test

Completed engines are hot tested in a 44 test stand area. The engines are generally run for 10 minutes at 1400 rpm. Minimum of one engine per day is given a complete test by the quality control laboratory. Tests are conducted at 1, 30, 600 hour runs with speeds up to 5000 rpm. A destructive test is conducted at 4200 rpm for 100 hours. Finished tested engines are then cleaned up, necessary repairs performed, and then sorted according to the engine variation codes as described in Section 3.1 Material and Production Flow. Engine drop basically consists of a temporary storage and then shipping. 90% of the engines are shipped by rail, the remaining 10% by truck. 85% of the engines are delivered to the U.S.; with the balance going to Canada.

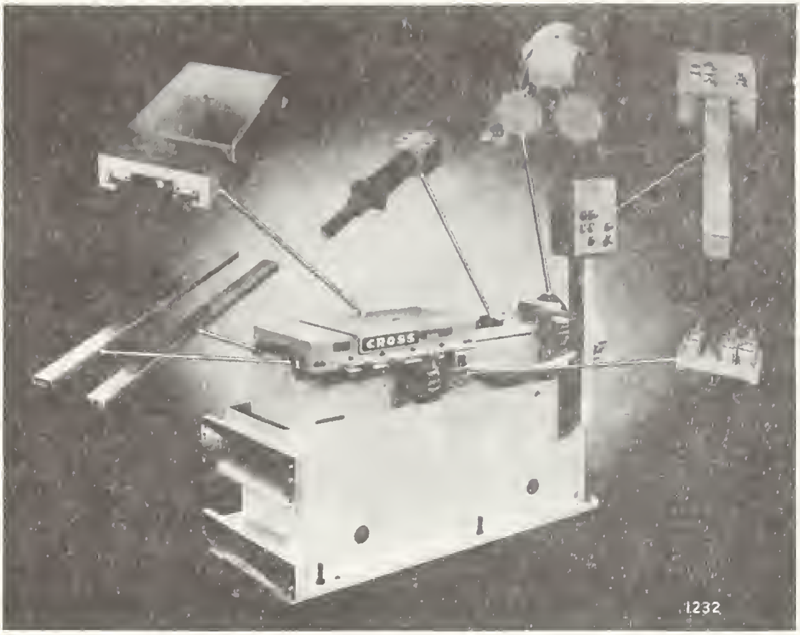
3.3 MACHINING PROCESS

The machining process of Plant #1 is accomplished by a series of automated transfer lines, called "Operations", consisting of groups of standard power tool modules. Each module or "station" performs a specific machining function such as drilling, milling, broaching, chamfering, reaming and tap. The number of modules on a given transfer line is determined by the complexity and number of total machining operations involved. With the exception of grinding and broaching, most of the cutting operations are performed by power head production units. A typical unit and its components are shown in Figure 3-9. The production unit includes a power motor, a head consisting of clusters of gears which drive spindles at selected speeds, and spindles with cutting tools and holders. A separate power unit feeds the tool head onto the work-in-process. Both the tool head production unit and its individually powered feed system are mounted on a rigid steel frame which is bolted to a concrete pad, providing a stable and precise positional reference to the transfer line.

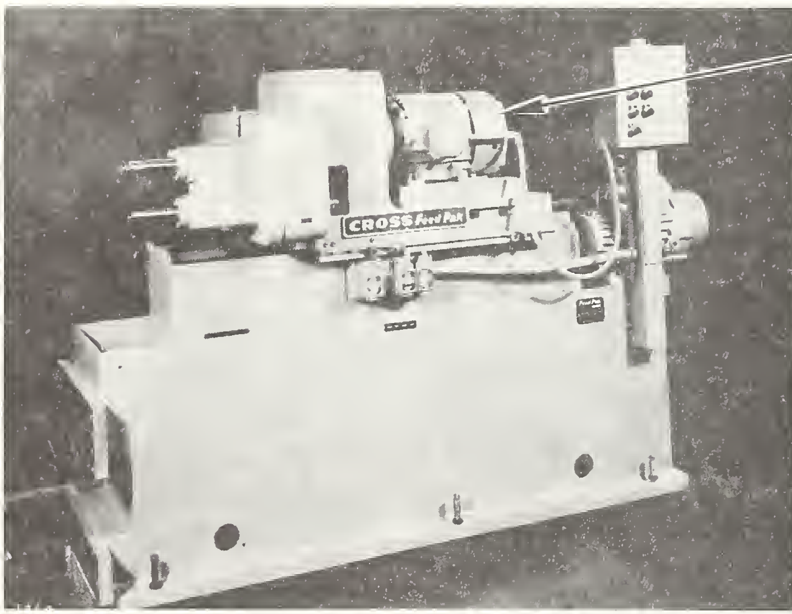
3.3.1 Precision Feed System

A major element of a power tool's accuracy is in the design of the feed unit assembly. The feed unit consists of hardened and ground flat steel ways upon which the tool head and its power unit are mounted. These ways guide the tool into the stock, with uniformity and precision of .0002 inches. Feed action is supplied by either mechanical or hydraulic drive units. The mechanical units transmit power via a splined shaft often using separate motors to provide a slow feed speed and a faster advance and recycling speed. A precision feed way for a standard drill unit is shown in Figure 3-10.

The machine tool production units are designed for high volume production while maintaining fairly precise cutting tolerances. Therefore, the tool units are restricted in their ability to accommodate changes. Small changes such as depth or diameter of cut which can be accomplished within the distances of the feed or



BASE WITH
POWER FEED



SPINDLE, HEAD,
POWER UNIT

COMPLETE UNIT

FIGURE 3-9 POWER HEAD PRODUCTION UNIT

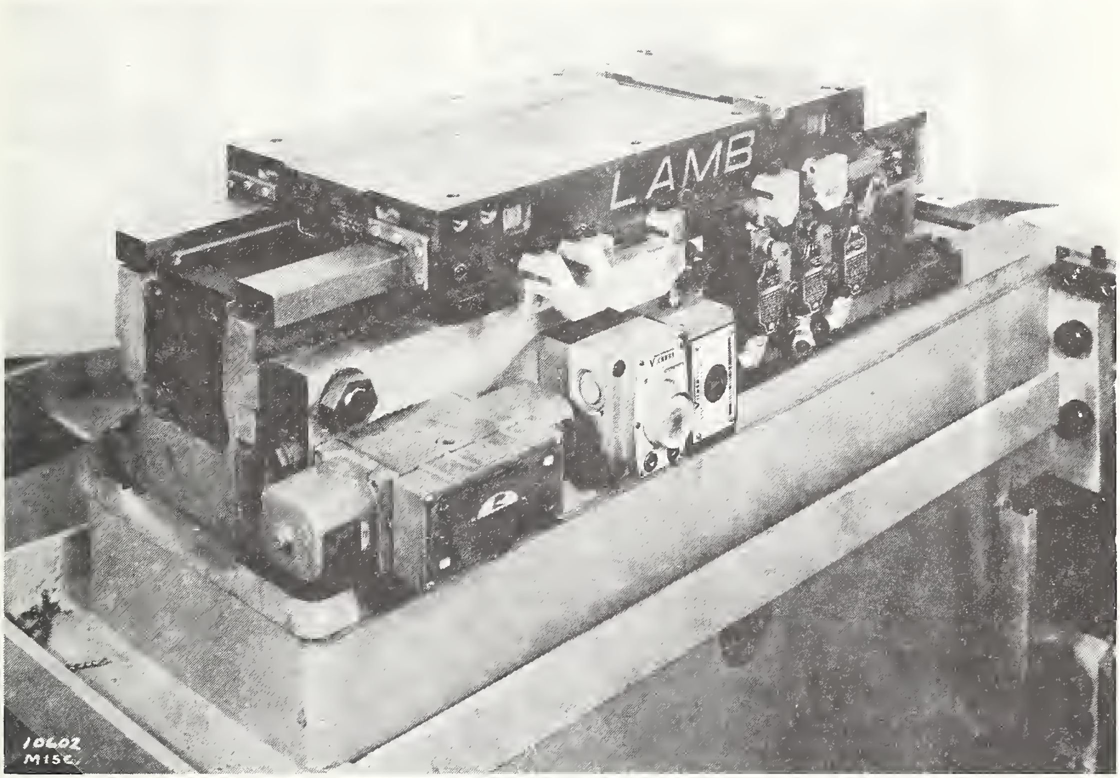


FIGURE 3-10 PRECISION WAY-TYPE FEED UNIT,
STANDARD DRILL UNIT

tool holder capacity, are easily instituted. Other changes such as new hole centers, or change in the surface geometry being reamed or milled, requires a complete all new tooling installation including a new base and its positional reference. These restrictions are characteristic of machine tool operations designed for high volume precision and repetitive machining operations as opposed to the more versatile numerical control systems that can accommodate more complex machining but at lower production capacities. The latter systems are typically used in manufacturing quantities of 20,000 units or less where set up time becomes a significant factor.

3.3.2 Transfer Line Automation

Work in process, or "stock" is indexed down a transfer line by several means of automation. A common practice is to move "stock" along supporting guide ways by means of an intermittently moving endless chain. The heavier engine components such as cylinder heads and blocks use this principle. Lighter components such as oil pumps, water pumps, intake and exhaust manifolds, use a chain type lift and carry system. Another method (a modification of the chain rail type system) consists of air or hydraulic pistons for indexing the parts. The fourth method employs mouting small parts onto unit fixtures which may either be moved by line automation on rails or by overhead lift-and-carry systems. None of the machining operations of the Windsor Engine Plant use this latter method (although they are used in engine assembly), principally because of higher costs.

Regardless of the line automation technique used, an accurate method for positioning and clamping the stock at each tooling operation is required. A designated "manufacturing" surface or a reference hole in the work-in-progress is often used to maintain positional reference.

3.3.3 Transfer Line Description

Figures 3-11 and 3-12 are typical examples of engine machining and line automation. In each illustration the transfer line is shown in the center with the individual power unit modules along either side. Figure 3-11, the work-in-process or stock is being machined simultaneously on both sides. Each of the power unit modules are fairly complex as indicated by the number of spindles in each of the heads. In this illustration, the power unit and the feeds are powered by separate motors. In Figure 3-12, the power feed for all of the tooling modules is provided hydraulically from a centralized hydraulic source. Each transfer line has its own electrical panel distribution system and supporting systems such as the cutting fluid distribution lines, exhaust ducts, and cooling systems. Certain broach operations require special DC power source with attendant AC to DC converters.

The individual tool heads are the working end of the machining process. Figure 3-13 is a close-up of a tool head from Operation 70 of block machining at Windsor that was removed for maintenance. A similar replacement unit is shown in Figure 3-14. The number of tool head clusters and spindles should be noted as well as the variations in their relative lengths or positions. In the Operations 70 example of Figure 3-13, two engine blocks are machined simultaneously, the complete operation being accomplished in two passes. Hundreds of these units in modular clusters on many transfer lines are required to complete the total machining of a complete engine.

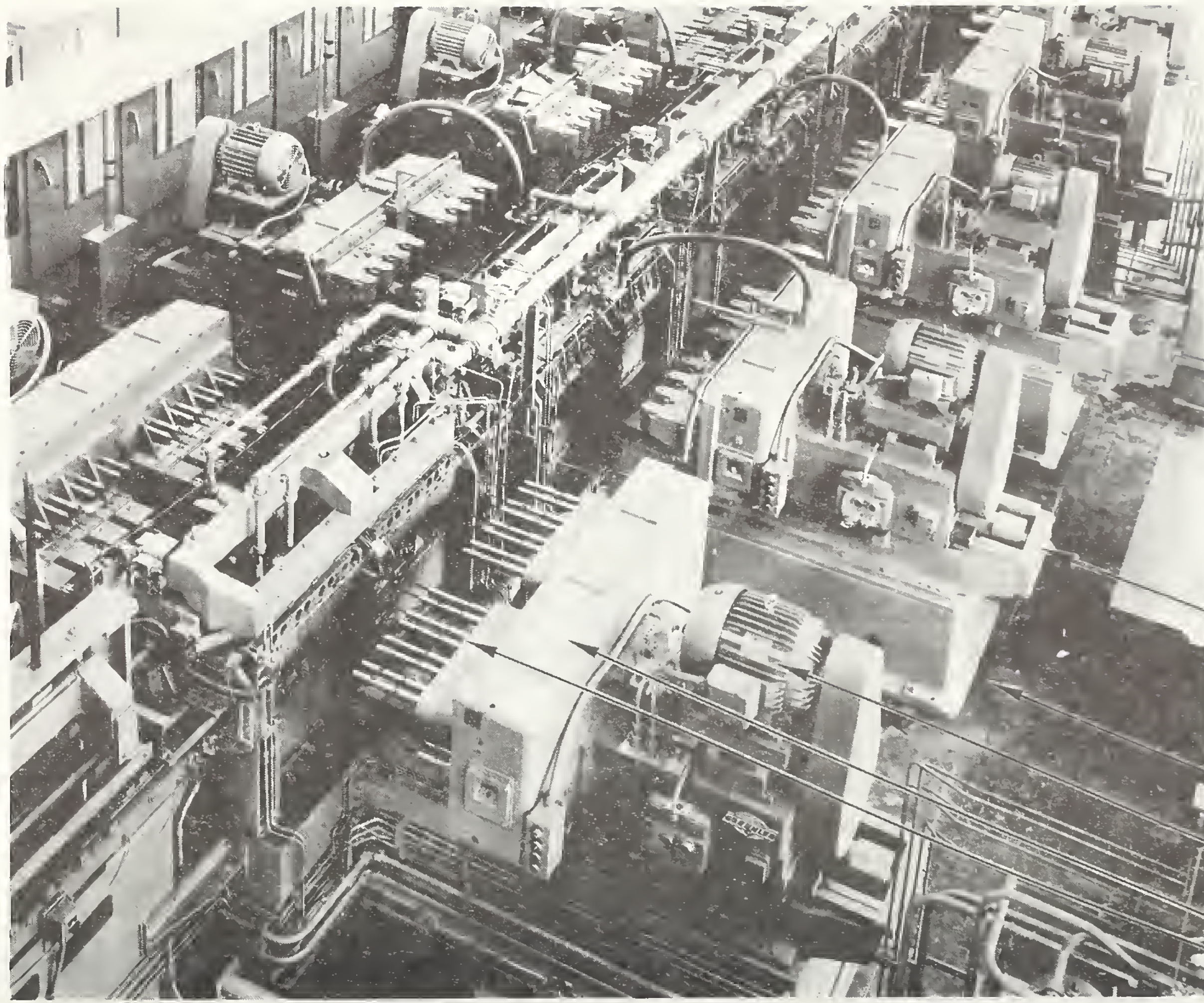


FIGURE 3-11 IN-LINE TRANSFER MACHINE - CONNECTING ROD MACHINING

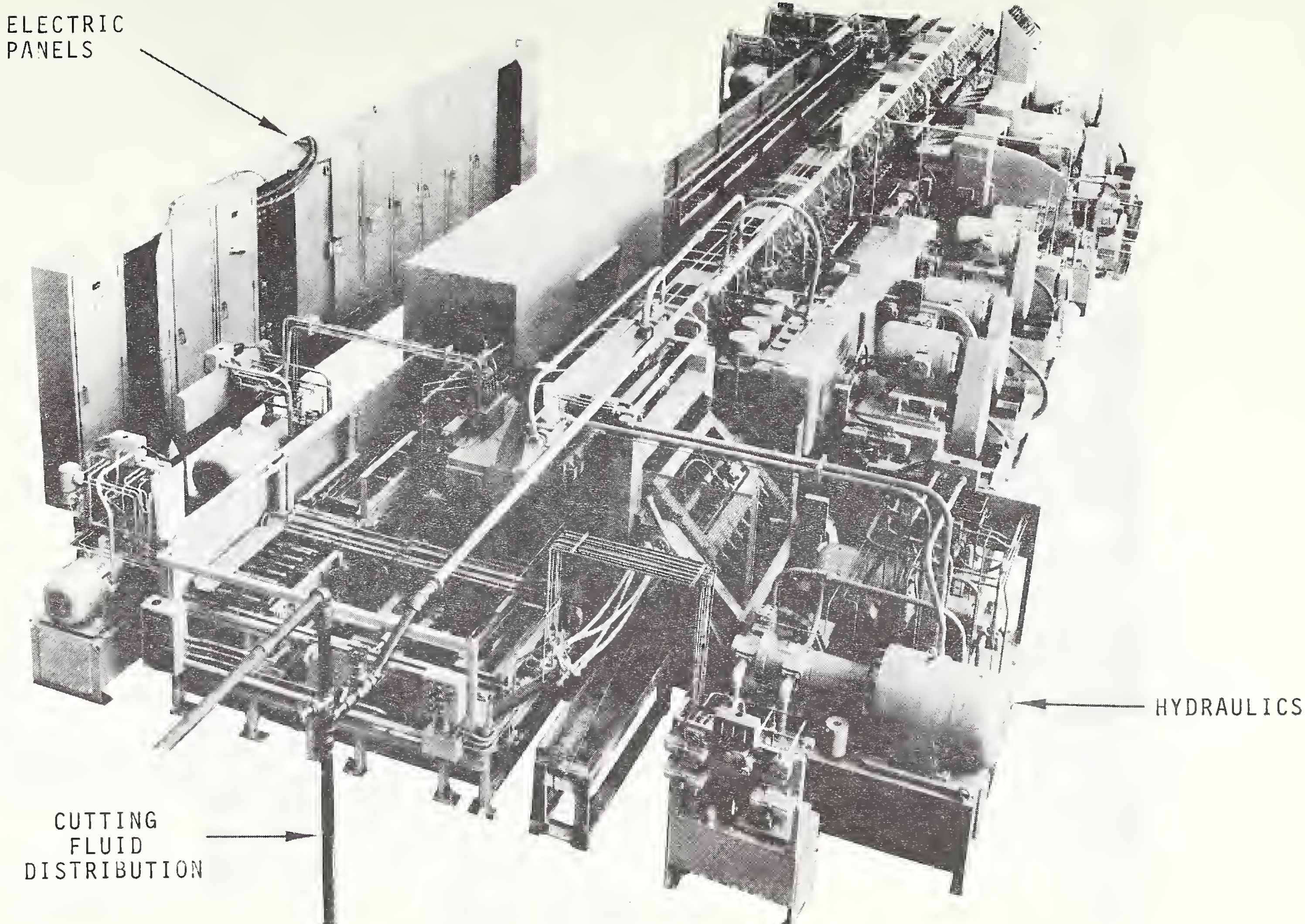


FIGURE 3-12. IN-LINE TRANSFER MACHINE - SUPPORTING FACILITIES

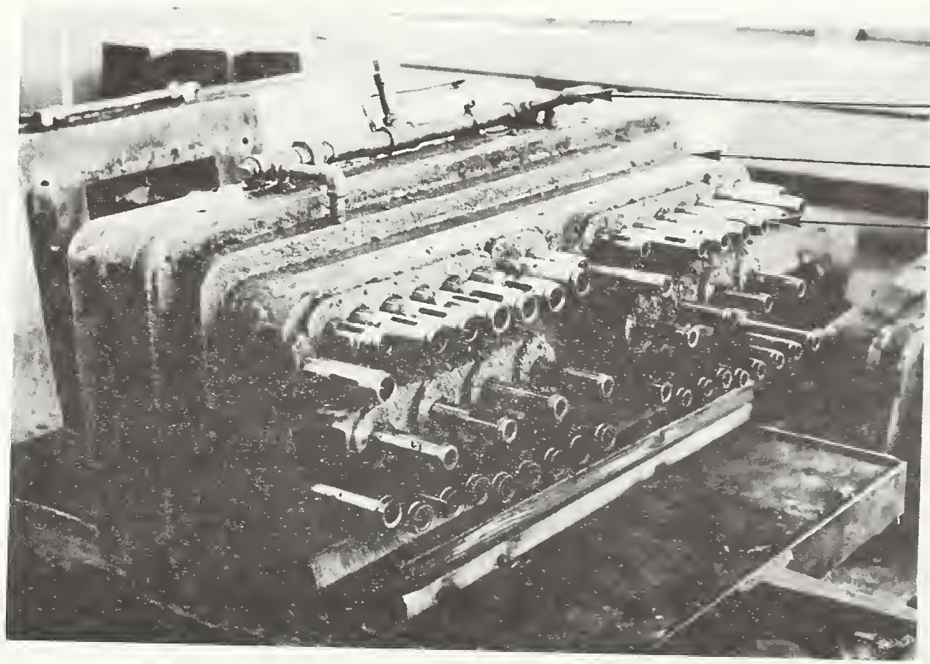


FIGURE 3-13 TOOL HEAD EXAMPLE - BLOCK MACHINING (OPERATION 70)

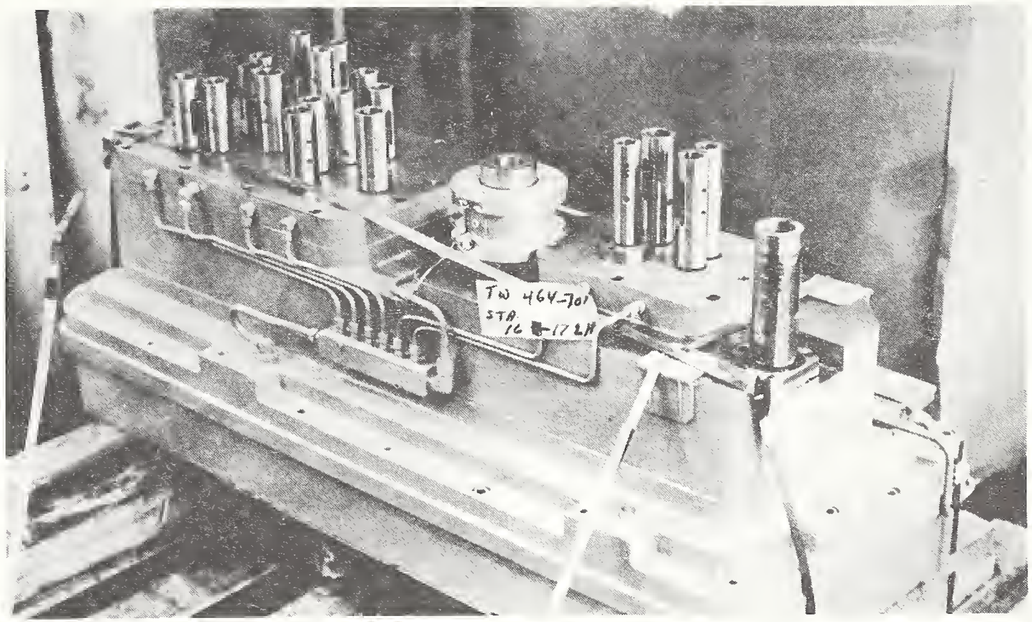


FIGURE 3-14 REPLACEMENT UNIT READY FOR INSTALLATION

3.4 MANUFACTURING METHODS

Engine manufacturing at Windsor is a highly procedurized and controlled process. Each machining and assembly operation has been thoroughly designed by manufacturing engineering to insure that the finished products, when produced in high volume, conform to drawing specifications. The manufacturing process also plays a main role in implementing engineering changes and design modifications. To gain a better picture of the complexities involved, a more detailed look will be given to specific machining operations, their sequence, the control processes employed, and the problems of insuring machine tool reliability through use of tooling service, maintenance, inspections, and floats.

3.4.1 Manufacturing Process

The principal methodology for controlling the manufacturing process is through use of process control sheets which describe each individual machining and assembly operation and sequence. Ford specifies this process at two levels of detail: 1) a description of the manufacturing operation that identifies the operations, sequence and capacities; and 2) a more comprehensive description of each of the machining and assembly operations, including detailed descriptions of cutting tools, specifications, operating speeds, and feed rates. Each individual tool is clearly identified with a code or serial number; the number of units required, as well as the hourly capacity.

A) Summary Level Process Sheet

Process sheets are made up for each major part or component of the engine that is to be machined and assembled. An example of a summary level process sheet for the cylinder block is shown in Figure 3-15. The basic identifying features of the part, such as the engine size, model year, material classification (a grade AC cast iron in this case), as well as the part number and the manufacturing department are provided. The process sheet shows that

FORD MOTOR COMPANY
MANUFACTURING OPERATIONS

ENGINE & FOUNDRY DIVISION — WINDSOR ENGINE PLANT — 8150

PROGRAM	PART NAME	ISSUE DATE	PART NUMBER
351 C.I.D.	CYLINDER HEAD	5-29-75 / 5-8-14	-6090-
FOR MODELS: 1975 MODEL	MATERIAL: ESE-M1A116-A (GRADE AC) CAST IRON; WT/LBS. ROH. FIN.; RELEASE		SHEET 1 OF 359

LINE NO.	OPER. NO.	OPERATION DESCRIPTION	TOOL - MACHINE - EQUIPMENT DESCRIPTION	UNITS REQ'D	TOOL OR S.T. NUMBER	HOURLY CAPAC. GROSS	NET
		SUMMARY					
1	10	FINISH BROACH TOP FACE, MANIFOLD	CINCINNATI BROACH		50086-NORTH		
2		FACES, TOP & SIDES OF BOLT BOSSES AND	(TWO WAY-HORIZONTAL)		50087-SOUTH		
3		SEMI-FINISH JOINT FACE.					
4							
5	20	MILL BOTH ENDS, DRILL BOLT HOLES, OIL	SPECIAL 87 STATION "LAMB"		50088-NORTH		
6		RETURN HOLES, PUSH ROD HOLES, DRILL	INLINE TRANSFER MACHINE		50089-SOUTH		
7		& TAP MANIFOLD HOLES, COVER MTG					
8		HOLES, END HOLES & CLEAN-OUT HOLES,					
9		DRILL STUD HOLES, DRILL & REAM CUP					
10		PLUG HOLES, DRILL, C'BORE, REAM &					
11		TAP SPARK PLUG HOLES, MACHINE					
12		SPRING BOSSES & VALVE THROATS					
13							
14	30	FINISH BROACH ENGINE JOINT FACE	LA POINTE BROACH		50090-NORTH		
15			(TUNNEL TYPE)				
16			CINCINNATI BROACH		50091-SOUTH		
17			(TUNNEL TYPE)				
18							
19	40	DRILL & SEMI-FINISH REAM VALVE	SPECIAL 15 STATION "LAMB"		50092-NORTH		
20		GUIDE HOLES, REAM STUD HOLES,	INLINE TRANSFER MACHINE		50093-SOUTH		
21		FINISH GUN REAM VALVE GUIDE HOLES,					
22		FINISH MACHINE VALVE THROATS & SEATS.					
23							
24							
25	50	WASH & FLUSH ALL FACES AND	"CENTR-SPRAY" WASHER		P-80020		
26		CAVITIES	(THRU TYPE)				
27							
28	55	PEEN VALVE STEM HOLES	AUTOMATION PEENING FIXTURE		16-ZE-5844		
29							
30		CHANGES:					
31							
32							
33							

PROCESS ENGR.	INDUSTRIAL ENGR.	DAILY SERVICE / DAILY PLANT PLANNING VOLUME	REQ. PER VEHICLE / REQUIREMENTS ____ PCS/HR. HOURS	NEXT ASSY.	OPERATION	SHEET 1 OF 359 / PART NUMBER
					SUMMARY	-6090-

FIGURE 3-15. SUMMARY LEVEL PROCESS SHEET

cylinder head machining is composed of a number of identified operations. Each operation represents a specific transfer line containing a number of machining actions such as mill both ends; drill bolt, oil return, and push rod holes. Each transfer line may have as many as 85 machining positions or "stations" made up of modular power tool units. The machining activities for operation 20, for example, is provided by an 83 station Lamb in-line transfer machine. The "north" and "south" designation under the tool number column indicates that there are two identical lines operating in parallel.* Some of the more significant information on the process sheet is the sequence of the machining operations which are designed to optimize machine tool application on cutting speed and throughput This takes into account that the work-in-process stock may require machining on more than one side, as well as both ends, and that the stock has to be indexed and clamped in position for each machining operation which in itself, if not carefully controlled, can consume a considerable amount of non-productive motion. Some machining operations have to be performed before others. Broaching of part surfaces is usually done first in order to provide a reference for positioning stock for subsequent operations.

B) Detailed Process Sheet

Each operation shown on the summary level sheet is defined further by a detailed process sheet. Figure 3-16 illustrates operation 170 for the cylinder block. For each tool used in the operation detailed specifications of the cutting characteristic, bore diameters and tolerances, as well as tool rotational speed and feed rate are given. Data in the detailed process area reflects the specifications requirements of the final product and as such becomes the basis for quality control.

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*Required to maintain sufficient production capacity since each engine requires two cylinder heads.

MFG. ENGR. JULY 69 4070

FORD MOTOR COMPANY
MANUFACTURING OPERATIONS

PROCESS SHEET

ENGINE & FOUNDRY DIVISION — WINDSOR ENGINE PLANT — 8160

PROGRAM	PART NAME	ISSUE DATE	PART NUMBER
351 CID	CYLINDER BLOCK	5-4-68 / 1-10-69	6010/15
FOR MODELS	MATERIAL / WT/LBS. RGH. FIN. / RELEASE		SHEET 566 OF

LINE NO.	OPER. NO.	OPERATION DESCRIPTION	TOOL - MACHINE - EQUIPMENT DESCRIPTION	UNITS REQ'D	TOOL OR B.T. NUMBER	HOURLY CAPACITY GROSS	NET
1	170	STATION #2 L. H. - IDLE	BORING HEAD	1	17-ZNB-2A-1343		
2							
3			FIXTURE	1	16-ZNB-2A-4319		
4		STATION #2 R. HAND	CLAMP INSERT	4	16-ZNB-2A-4319-D32		GS
5			LOCATOR ROUND	1	56-Z -7121-D20		GS
6		SEMI-FINISH BORE (2) CYLINDER	DIAMOND	1	56-Z -7121-D19		GS
7		BORES IN THE LEFT BANK TO					
8		3.975 - 3.981 DIA.	CUTTER ASSEMBLY R. H.	2	13-ZNB-2A-412-D201		
9			CUTTER BODY	2	13-ZNB-2A-412-D1		
10		BORES #5 AND #8	BLADE	24	84-63-1593		GS
11			WEDGE	24	56-ZE-500-D10		GS
12		R. P. M.	RETAINER SCREW	2	48-60-1912		GS
13		S. F. P. M.	WASHER	2	48-60-1930		
14		FEED/REV.					
15		FEED/MIN.					
16							
17		SEMI-FINISH BORE (2) CYLINDER	CUTTER ASSEMBLY L. H.	2	13-ZNB-2A-412-D202		
18		BORES IN THE LEFT BANK TO	CUTTER BODY	2	13-ZNB-2A-412-D2		
19		3.975 - 3.981 DIA.	BLADE	24	84-63-1593		GS
20			WEDGE	24	56-ZE-500-D10		GS
21		BORES #6 AND #7	RETAINER SCREW	2	48-60-1913		GS
22			WASHER	2	48-60-1930		GS
23		R.PM.					
24		S.F.P.M.					
25		FEED/REV.					
26		FEED/MIN.					
27							
28							
29							
30							
31							
32							
33							

PROCESS ENGR.	INDUSTRIAL ENGR.	DAILY SERVICE / DAILY PLANT PLANNING VOLUME	REQD. PER VEHICLE / REQUIREMENTS ____ PCS/HR. HOURS	NEXT ASST.	OPERATION	SHEET 566 OF / PART NUMBER
E. JACOBSON / N. J. KIPPS					170	6010/15

FIGURE 3-16. DETAIL LEVEL PROCESS SHEET

3.4.2 Cylinder Head Machining

A more graphic presentation of cylinder head machining is shown in Figure 3-17 along with the relative positions and sequence of all operations. The basic operations of mill, drill, ream, tap, and counter bore, identified as operations 20A through 20D, are performed by a four segment transfer line. The floor plan of the first segment or operation 20A is shown in Figure 3-18. In this diagram the duplicate or parallel operations (north and south) for head machining can be seen. The cylinder heads arrive into operation 20 from broaching (operation 10) via an accumulation shuttle and move from right to left down the center of the transfer line. The accumulation shuttle consists of a rail guide way with an endless chain transport. Once the stock reaches the machining operation, transfer line automation takes over the sequencing through each of the machine tool stations. Individual machine tool units are identified by the rectangular blocks perpendicular to the transfer line's center. Although there are 21 numerically designated stations in this example, only half of them are actively occupied by machine tool positions. Five modularized power tool units are located on the right side of the transfer line and six including a double unit are located on the left. From the position of the power tool units, it can be seen that the stock is machined simultaneously on both sides. The cylinder head exits station 20A and proceeds again by line shuttle automation on to the subsequent machine tool operation, operation 20B. A photograph taken from the exit point of 20A looking back up the center of the transfer line is shown in Figure 3-19. In this picture the drill spindles of station 17, 18, and 19 are clearly visible. Cylinder heads are oriented on edge, lengthwise to the direction of travel of the line. The individual power units for each of the tool operations can be seen further down the line as well as the exhaust ducts for removing smoke and fumes from the cutting operations.

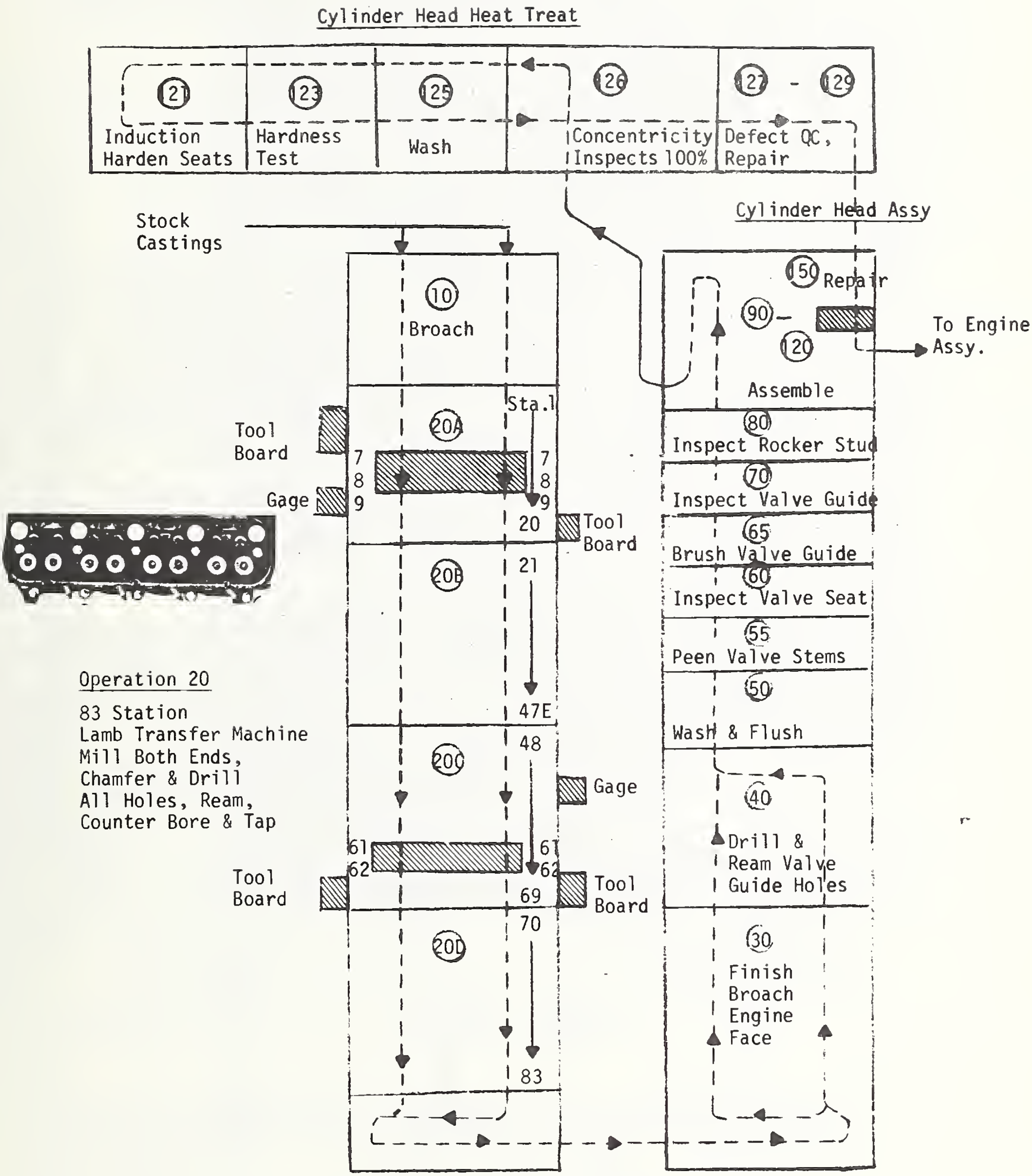
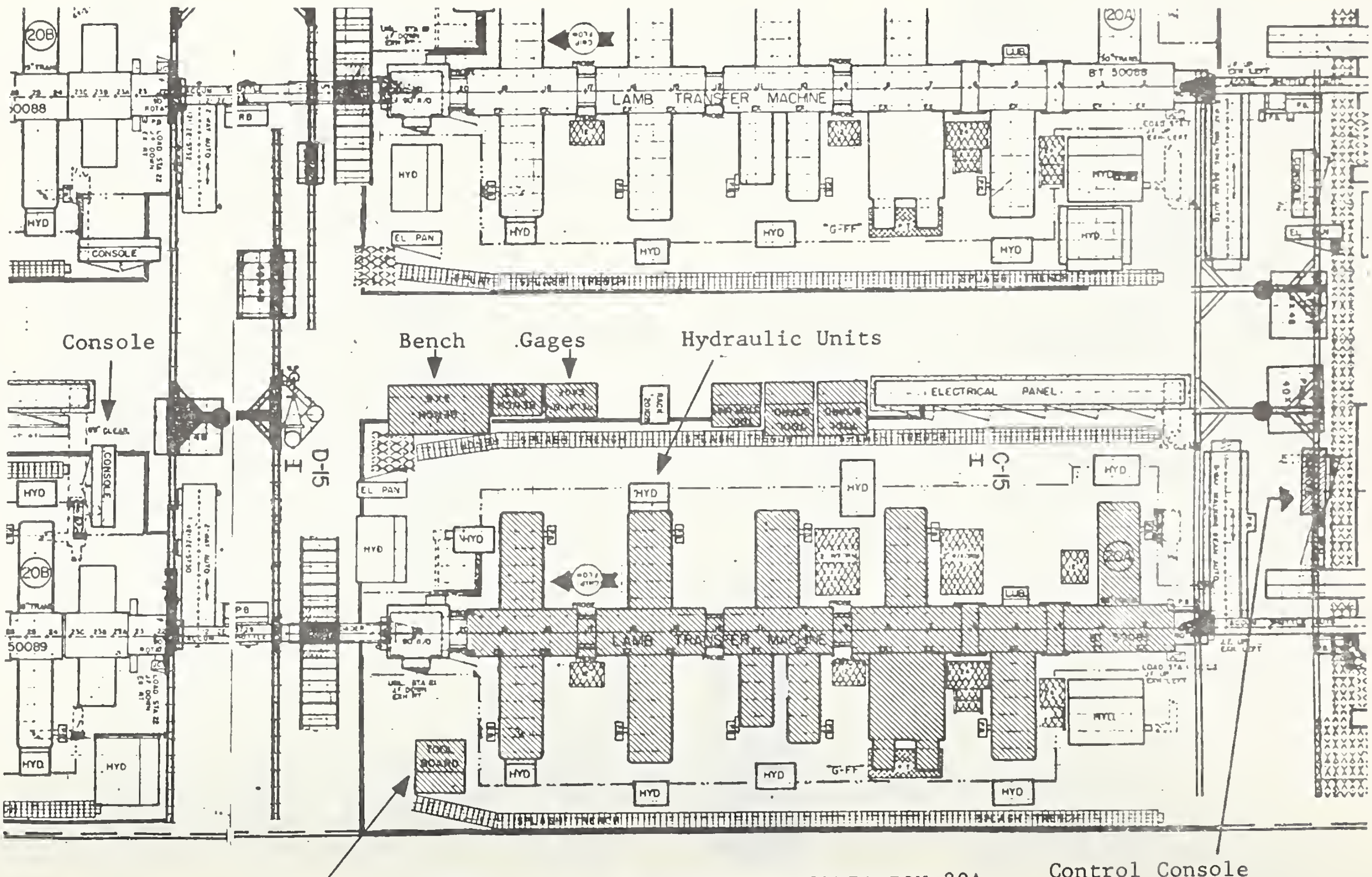


FIGURE 3-17. CYLINDER HEAD MACHINING



Tool Board

FIGURE 3-18. HEAD MACHINING-OPERATION 20A
STATIONS 1-21 (MILL, CHAMFER, DRILL AND REAM)

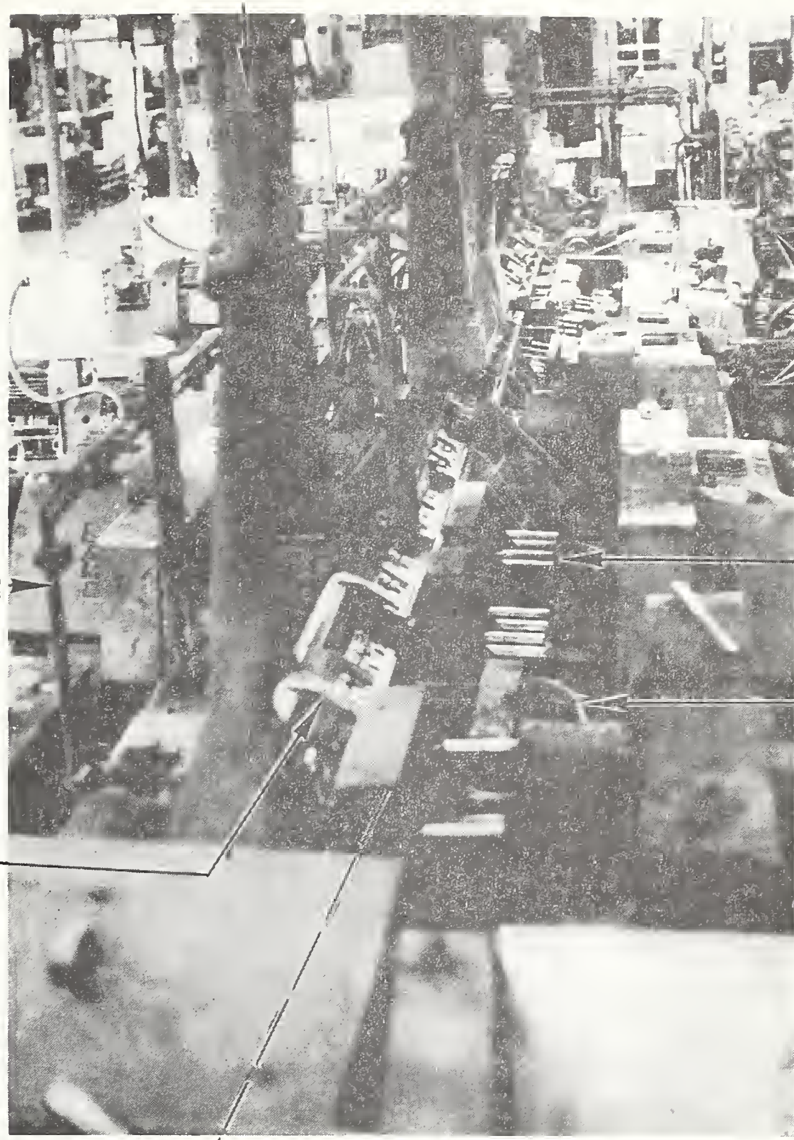


FIGURE 3-19 OPERATION 20A - HEAD MACHINING (LAMB TRANSFER MACHINE)

A closer view of the cutting tool engagement is illustrated in Figures 3-20 and 3-21. This activity was taken at station 8 consisting of drilling and chamfering the cover mounting and rocker arm bolt holes. The principal elements identified are the tool head assembly, consisting of individual spindles and cutting tools or drills clustered in rows. The depth of cut is controlled by the actual extension of each cutting tool distance from the head assembly, since engagement distance is set by tool head feed. Cutting lubricant, a mixture of water and oil at a 20 to 1 ratio is directed by individual lines to each of the cutting surfaces.

3.4.3 Supporting Facilities

Referring again to the layout plan, Figure 3-18, a number of supporting facilities and other equipments are identified. These essential facilities for each transfer line operation are: hydraulics, control console; inspection stations and gauges; maintenance benches; chip removal with elevators and bins. The individual power units for station 8 described above are shown in Figure 3-22. The upper two units power the head tool units directly while the lower units provide power for feed. Tool engagement sequence retraction is monitored and controlled from a centralized panel shown in Figure 3-23. An outline of the transfer line illustrated in the floor plan of Figure 3-18 is actually mounted right on the panel face. Numerical labels identify each station position with those stations containing active tool power units identified by lighted indicators. The indicators also show what tools are in operation at a given instant of time as well as where they are in the cycle. Each tool's operation is synchronized to the position of the stock as they index down through the transfer line. Audible alarms and warning sensors are also available which automatically shut the line down in the event of malfunctions. The dial indicator is a cycle timer for determining the sequence time of a particular machine tool operation.

DRILL AND
CHAMFER
COVER
MOUNTING
HOLES AND
ROCKER ARM
BOLT HOLES

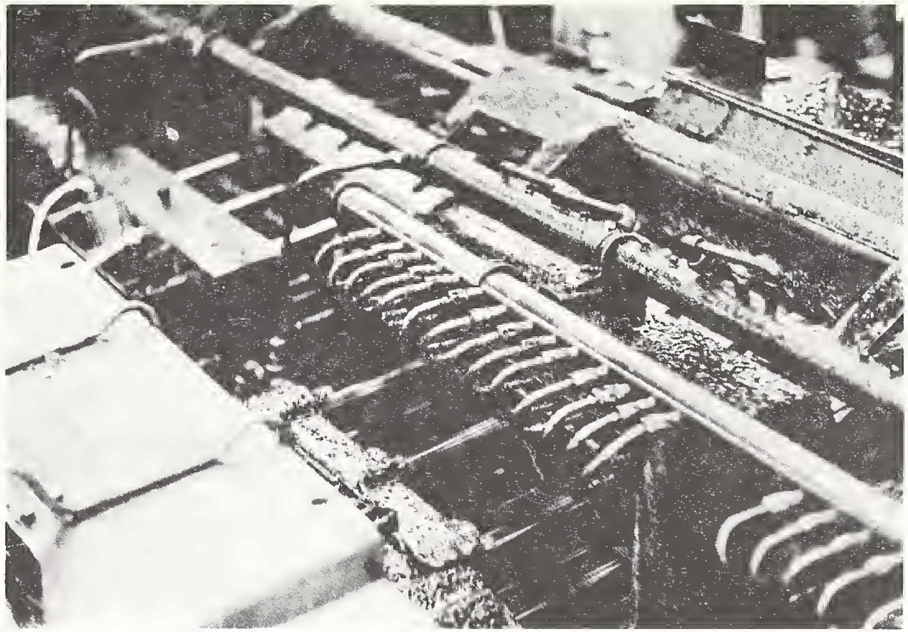
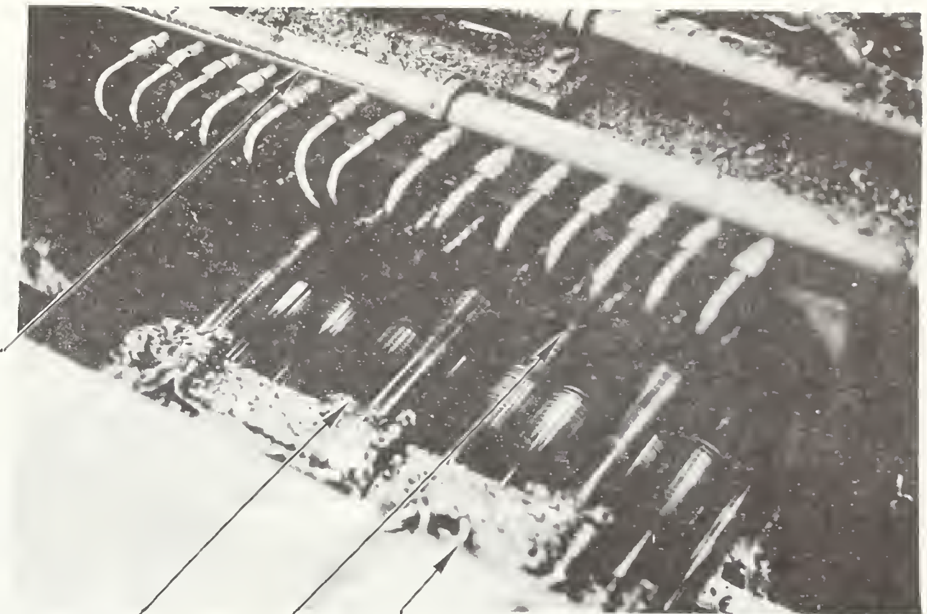


FIGURE 3-20 STATION 8 - TOOL HEAD



TOP ROW: 3 COVER MOUNTING HOLES

MIDDLE ROW: 8 ROCKER ARM BOLT HOLES

FIGURE 3-21 STATION 8 - CUTTING TOOL ENGAGEMENT

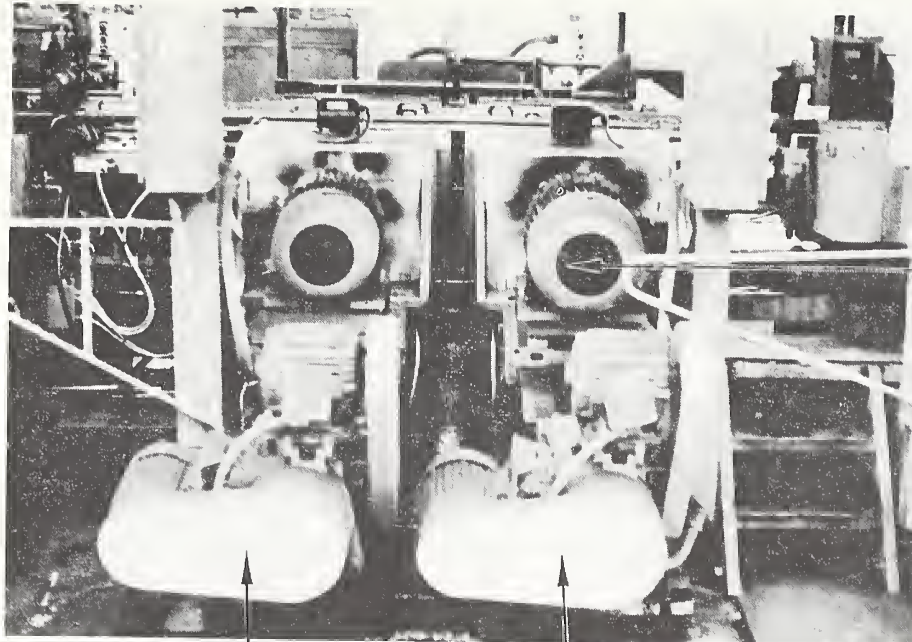


FIGURE 3-22 POWER UNITS

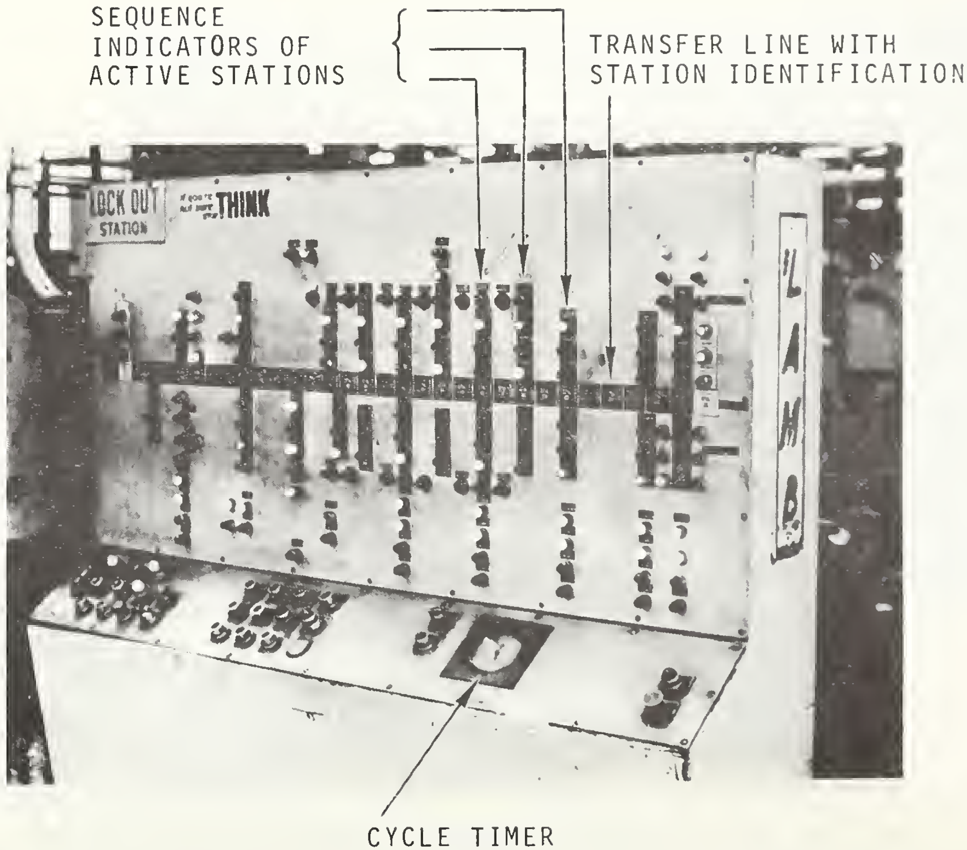


FIGURE 3-23 CONTROL CONSOLE

The indexing or movement of the cylinder heads between each machine tool operation is done hydraulically. This same system provides the forces to clamp the unit at each machine tool operation prior to tool engagement. In Figure 3-18 five hydraulic units are located on the right and left hand side of the transfer line.

Cutting tools have to be replaced continuously based upon wear and erosion of tolerances. Tool replacement and servicing will be discussed in more detail subsequently; however, periodic quality checking of work in progress has to be performed. These functions are provided by the gauging stations shown on the diagram. A close up of a cylinder head gauging station for operation 20A is shown in Figures 3-24 and 3-25. These fixtures are hand made at a cost of as much as $30,000 each. Upon completion of operation 20A a sample cylinder head is pulled off the line onto a side conveyor and placed in the gauge fixture. Each hole or surface performed in operation 20A is checked accurately against prescribed limits by a dial indicator gauge. The test results are recorded and entered into a log. Normal frequency of quality control checks would be one sample an hour. These checks would be performed more frequently under conditions in which tool change had been instituted into the machining operation or abnormal tool wear was suspected.

Occasionally, either due to tool breakage or machine tool malfunctions, work-in-process must be removed from the line and repaired manually. Maintenance facilities are spotted periodically along the transfer lines for this purpose. The maintenance bench for cylinder head repairs in Figure 3-26 is typical and their relative placement with respect to the machining line is also indicated in Figure 3-18.

Another problem is chip stock removal from the machine tool areas. The amount of chips generated is significant as attested by the multiplicity of cutting operations being performed at each of the machine tool stations. Facilities to expedite the removal of

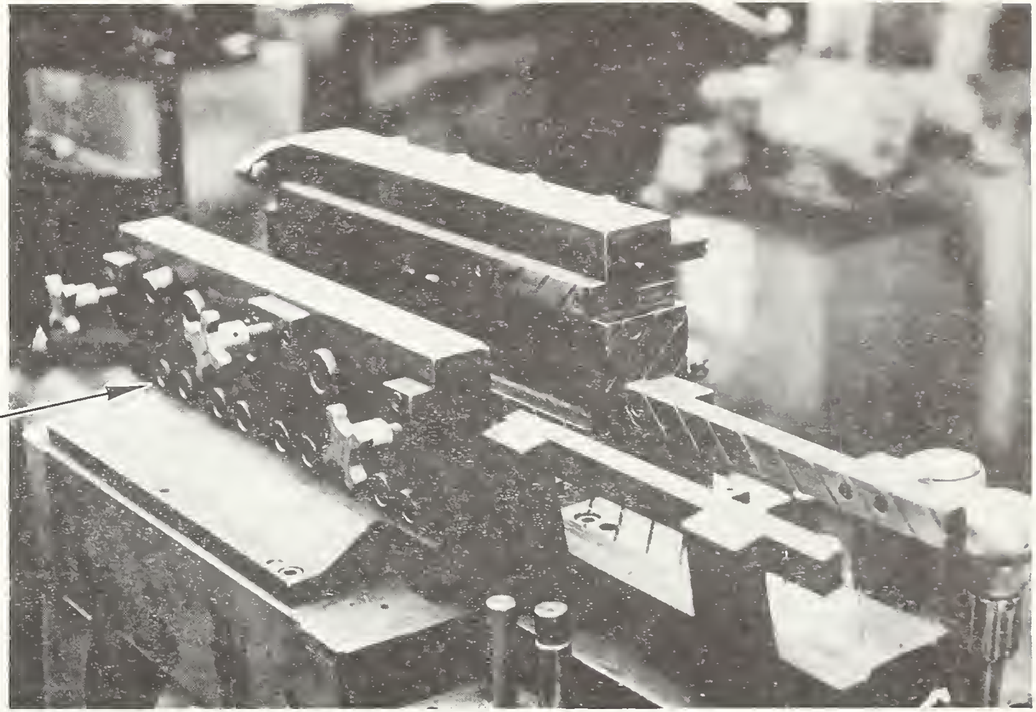


FIGURE 3-24 HEAD GAUGE - OPERATION 20A

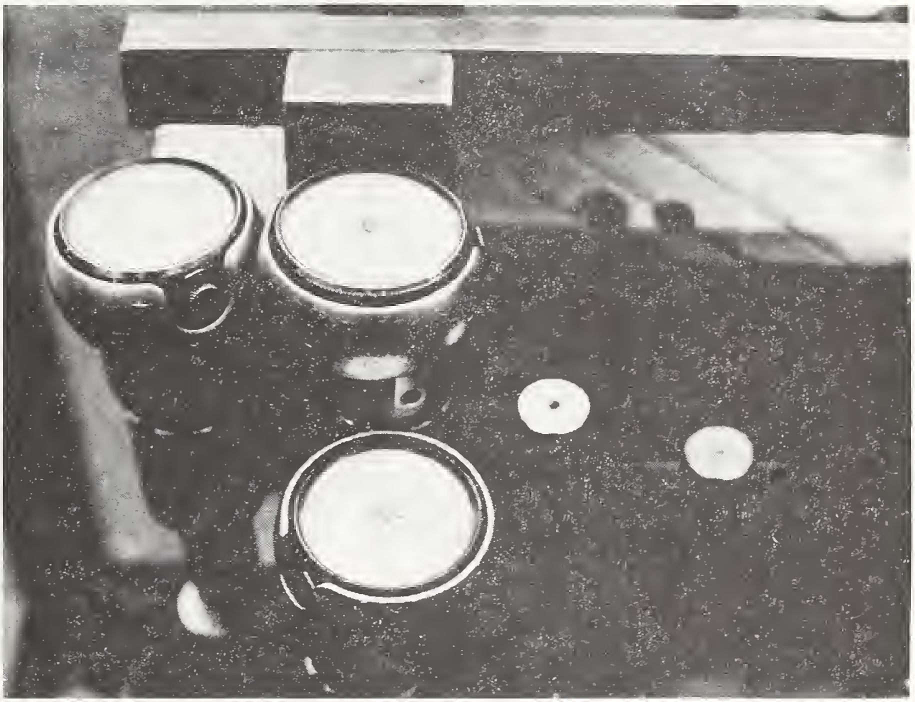


FIGURE 3-25 DIAL INDICATORS

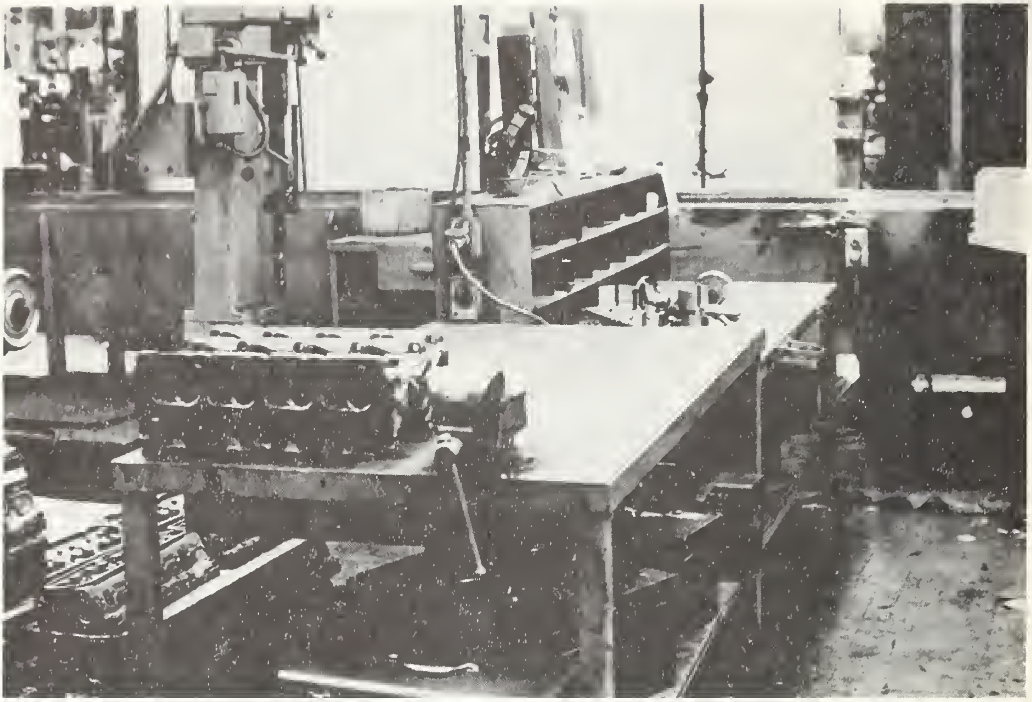


FIGURE 3-26 MAINTENANCE BENCH - HEAD REPAIRS

excess chip stock is designed into the transfer line system. The facility usually consists of a moving conveyor system running underneath the length of the line with contents being removed at a common junction point at the end or between adjacent transfer lines. Secondary conveyor systems transport the chip stock to a central clarification system or portable bins for disposal. A typical elevator and bin near operation 20A is shown in Figure 3-27.

The foregoing facilities are specific systems designed to serve each individual machine tool operation. Other facilities such as those listed in Table 3-2 are operated on a larger scale and usually support several areas of manufacturing. Under the auspices of plant engineering, they represent as much as 20% of total plant investment cost. Maintaining machine tool systems at a proper temperature requires the installation of 20 central coolant systems at a cost of $400,000 apiece. To provide proper ventilation over the total manufacturing area, 300,000 cubic feet per minute of air is exhausted while another 300,000 cubic feet per minute are intake. These facilities cost in the range of $450,000 apiece.

The chip conveyors previously mentioned, average 60 feet in length. A typical installation might cost in the range of $250 per linear foot.

Close-up photographs showed the extent of cutting oil distribution systems involved in each of the major machine tool operations. Windsor Plant No. 1 extracts 6,000 gallons of usable oil per week. Water is recovered from the cutting oil systems and recirculated at a rate of 300 gallons per minute.

Other plantwide facilities include compressed air at 1,500 cubic feet per minute at 100 pounds per square inch. This system runs about $3 million per installation. Although the hydraulic oil for transfer line operation is recirculated, a topping off system is still required to replenish oil that is lost.

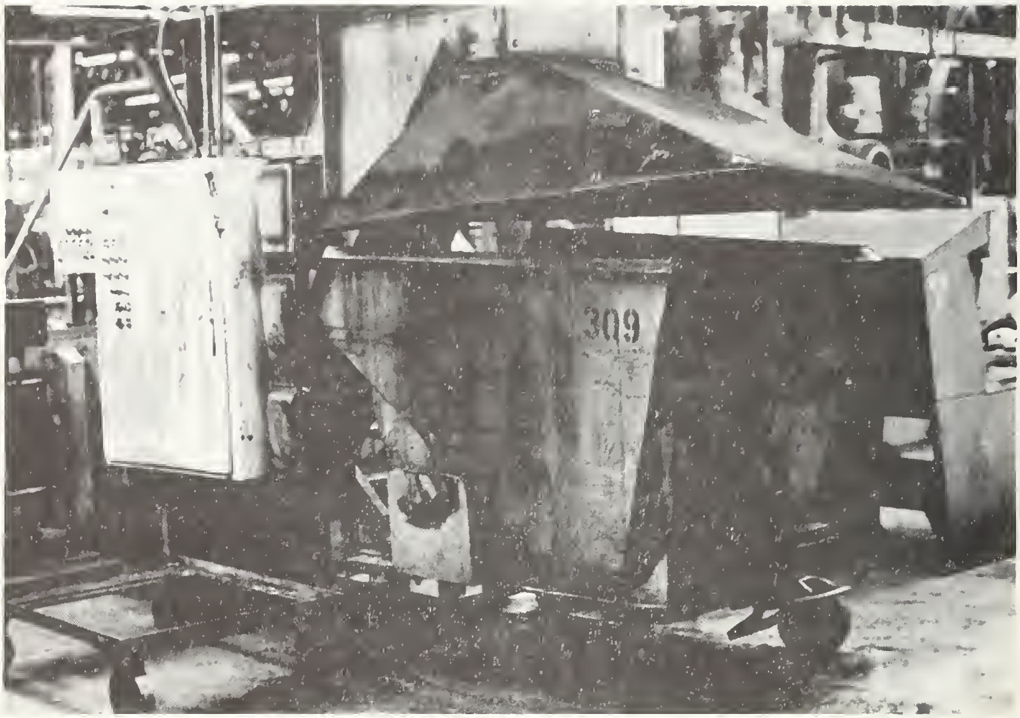


FIGURE 3-27 CHIP ELEVATOR AND BIN

TABLE 3-2. SUPPORTING FACILITIES

DESCRIPTION	QTY/CAPACITY
Central Coolant Systems	20
Chip Conveyors (60 ft. average)	50
Water Recovery (cutting lubricant)	300 gal/min.
Ventilation System	
Intake	300 CFM/min.
Exhaust	300 CFM/min.
Compressed Air	1500 CFM @ 100 psi
Pressure Hydraulic Oil	--
Make-up System	
Power Converters	AC to DC

The topping off tanks cost about $200,000 an installation.

Other facilities include century spray index and transfer type washers for cleaning work-in-process stock after machining operations. A considerable quantity of bridge cranes are also used to handle stock transfers, gauging, and floats.

3.4.4 Cylinder Block Machining

A good perspective on the variations and complexities of machining can be gained by examining the total production process of a particular part, such as the cylinder block. Of particular interest are the sequence of machining operations; block orientation as it progresses through the transfer lines; the material handling methodology, inspections, and floats.

As mentioned previously, a major responsibility of manufacturing process is the determination and specification of the optimum sequence of the machining operations. Each machining operation involves a certain element of time, the duration of which affects line capacity or throughput. Thirty stations per transfer line operation appear optimum for controlling throughput and servicing. Current production requirements dictate a throughput of about 55 blocks per hour, an average of little over a minute for each machining cycle. Within this duration, the stock must be indexed into place, clamped, tool bit engaged, cutting action performed, tool bit retracted, clamp released, and stock then indexed to the next station. Tool engagement time is determined by type of cutting operation and depth. Consequently, a hole several inches in depth, may have to be done in more than one pass. Table 3-3 identifies all of the machining operations for the cylinder block. As may be observed, most of the machine functions are drilling, as expected in all good castings, where very little additional stock needs to be removed. However, the first operation is mill and broach. This primarily provides a smooth working surface for subsequent drilling operations as well as a reference location for cylinder block positioning and clamping. It should be noted that all faces of the cylinder block require some kind of machining. Several of

TABLE 3-3. CYLINDER BLOCK MACHINING SEQUENCE

	Machine/Tool Operation		Block Surface					
Oper. No.	Function	Application	Top	Bottom	Front	Rear	Right Bank	Left Bank
10	Mill	Locating Lugs	X					
	Broach	Locating Lugs	X					
20	Broach	Banks, Bearing & Pan		X				
30	Drill Chamfer And Ream	Manufacturing Holes		X				
	Mill	Bearing Sides		X				
40	Bore	Cylinders	X					
50	Mill	Front And Rear Face			X	X		
60	Drill Chamfer Counter Bore Ream	Holes	X	X				
70	Drill Chamfer Counter Bore Ream	All Holes			X	X		
80	Drill	Oil Holes		X				
	Bore & Ream	Side Cup Holes					X	X
	Drill & Chamfer	Carrier & Water Drain Holes					X	X
	Mill	Manufacturing Pads					X	X
90	Drill, Ream Chamfer & C/Bore	Holes					X	X
	Mill	Manufact. Pads					X	X
100	Drill Chamfer Ream	Tappet Holes	X					
110	Tap, Probe & Blow-Out	All Holes	X	X	X	X		

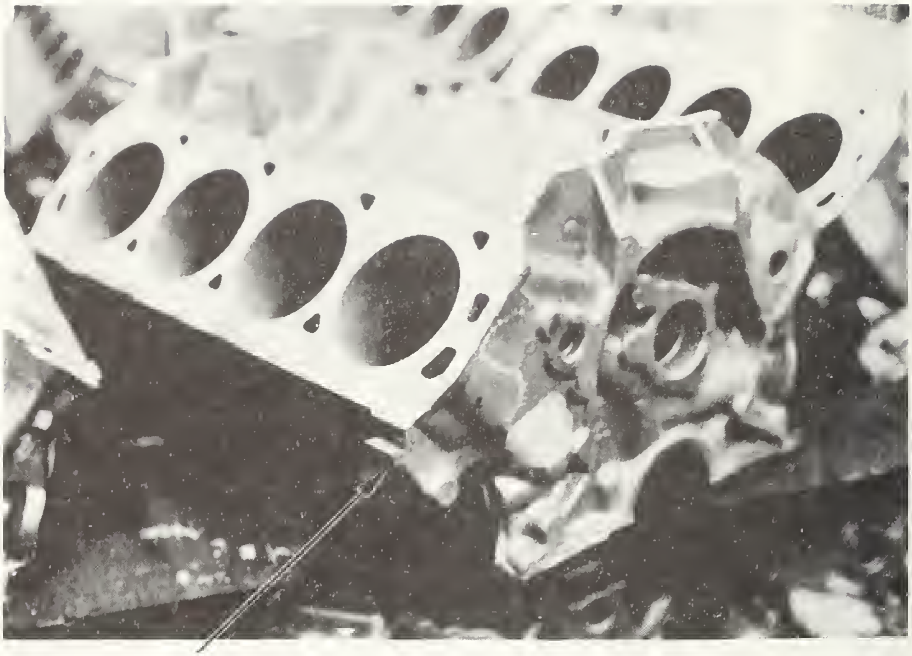
- Denotes reference surfaces and holes to align block for subsequent machining operations.

TABLE 3-3. CYLINDER BLOCK
MACHINING SEQUENCE (CONTINUED)

Oper. No.	Machine/Tool Operation		Block Surface					
	Function	Application	Top	Bottom	Front	Rear	Right Bank	Left Bank
114R	Repair	Drilled & Tapped Holes						
120	Wash & Blow-Off	Complete Block	X	X	X	X	X	X
125	Assemble	Main Bearing Caps						
130	Torque	Main Bearing Bolts (10 Spindle Nut Runner)						
140	Chamfer & Bore	Cam Bore & Crank Holes			X	X		
	Ream	Dowel Holes				X		
	Semi-Finish Bore	Distributor Shaft Hole	X					
	Face & Chamfer	Thrust Bearings			X	X		

these surfaces are machined simultaneously. It is the balancing out of the number of machined faces in conjunction with specific tool operation performed that optimumizes throughput of work-in-process. In some instances, the type of the machine tool function determines its location in the sequence. For example, all tapping functions are consolidated at Operation 110, mainly because of the need for a different type cutting lubricant than that used in normal drilling operations. Beyond Operation 110, the functions are mainly repair, assembly, inspection, and cleaning. Also, the right and left bank cylinder faces are not final milled until after boring of the crank shaft centers. This is to insure that a .018 inch tolerance is maintained from the center line of the crank shaft and the left and right bank cylinder faces.

The raw cylinder block castings for machining arrives from the Windsor Casting Plant on pallets. In Figure 3-29, stacks of palletized blocks are waiting at the beginning of broach, Operation 10. A close up of the locating lugs used for subsequent referencing of machine operations is shown in Figure 3-28. A layout of a typical cylinder block transfer line is shown in Figure 3-30 for Operation 70. As indicated from Table 3-3, this operation basically drills, chamfers, counter bores and reams all holes on the block front and rear faces by use of a Burr 24 station transfer machine. The supporting functions are more clearly identified in this illustration. Note the presence of tool boards, maintenance benches, chip elevators, stock removal conveyors, hydraulic units, and 2-way hoists. Inspection facilities are provided at the beginning and the end of each machine operation. Associated with these stations are palletized stock of work-in-process up to that point. These floats are intended for two purposes: 1) to provide accessibility of stock for periodic inspection during the shift and 2) a means for stockpiling work which can be entered into the job stream in the event of failure or momentary shutdown of preceding operations. A float build up of an hour's amount of stock permits periodic shut down of a particular station for tool bit replacement and maintenance. The number of floats and inspection stations for each transfer



LOCATING LUGS

FIGURE 3-28 ROUGH BLOCK CASTING

PALLETIZED STOCK - 24
BLOCKS PER PALLET

FIGURE 3-29 COMMON MATERIAL HANDLING PROCEDURE FOR START OF OPERATIONS AND FLOATS

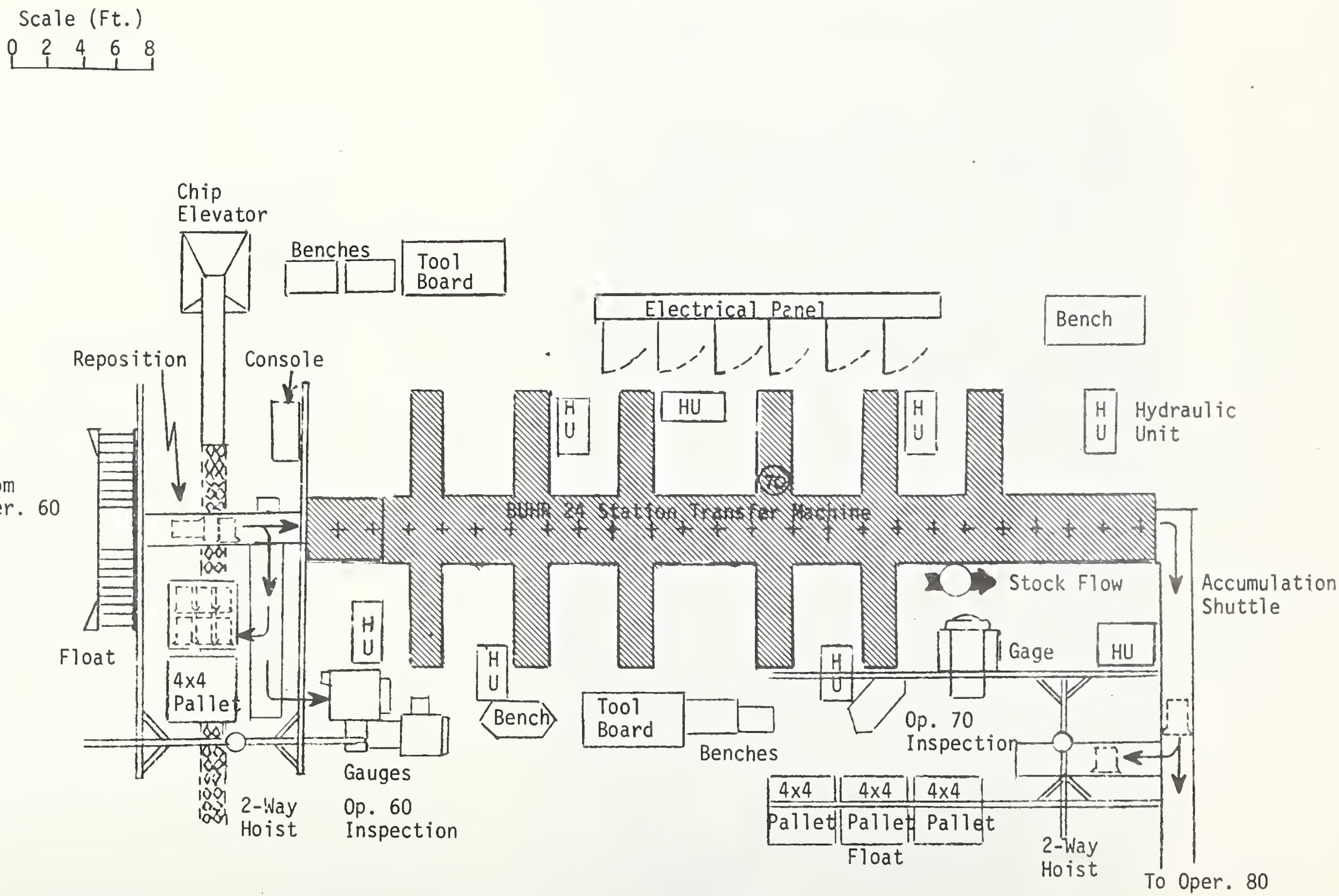


FIGURE 3-30. OPERATION 70
CYLINDER BLOCK MACHINING

line is identified in Table 3-4. For a complete cylinder block machining, 13 inspection stations are used. A float of partially machined stock has been established between each of the machine operations making a total of 18 floats for all of cylinder block machining.

A summary of all transfer line activity for each major engine part is contained in Appendix A. The machine tool production units are provided by many different suppliers as the tables attest. Generally, a specific supplier will specialize in a certain aspect of the machine tool process, such as pistons, cylinder head, or cylinder block machining.

TABLE 3-4. INSPECTION AND FLOAT REQUIREMENTS
CYLINDER BLOCK MACHINING

Inspection/Gage	Qty	Float	Operation Location
			Between:
x	(1)	x	10 and 20
x	(2)	x	20 and 30
		x	30 and 40
x	(3)	x	40 and 50
x	(1)	x	50 and 60
x	(2)	x	60 and 70
x	(1)	x	70 and 80
		x	80 and 90
x	(2)		90 and 100
x	(1)	x	100 and 110
		x	110 and 120
		x	120 and 130 Bearing Assem.
		x	130 and 140
x	(1)	x	140 and 150
x	(1)		150 and 155
x	(1)	x	155
		x	160
x	(1)	x	160 and 170
x	(1)		170 and 180
			180 and 190
		Double Float	190 and 200
Repair		---	200 and 210
Repair			210 and 220
Repair			220 and 230
Repair			230 and 240

Summary Requirements

Inspections - 13 (Use of 18 Gauges)

Repair - 4

Float - 18 (Approx.)

3.4.5 Tool Operations

A major manufacturing problem associated with high volume machining operations, is the monitoring of tool wear and the development of replacement procedures. As suggested by the scope of the total manufacturing operations of Windsor Plant No. 1, the total quantity of tools in use at any single time run into the thousands. Manufacturing engineering has long specified the very best of tool materials and design criteria. However, tool wear is never eliminated and it must be constantly monitored. Cutting tolerances are typically held within several ten-thousandths. Tools are replaced long before they break or tolerances become excessive. A typical 24-station transfer line will replace all bits at least once a shift and in some instances as often as twice a shift.

A) Cutting Tool Characteristics

A major contribution towards extending the life span of a tool's cutting edge was the improvement in the design features of standard twist drills. This improvement stemmed from a change in the cutting geometry of the drill face. For many years, the standard of industry was the straight lip of the common jobbers drill. From the observation of wear characteristics it was found that by designing the drill with a radial lip, its life increased significantly. Figure 3-31 compares the standard and radial lip designs for a 3/8 inch standard shank drill. Differences in performance characteristics between the conventional and modified drill points is shown in Figure 3-32. Drill life went from 42 to 84 pieces under the same cutting speed conditions. Bit lives between 2000 and 5000 operations are typical at Windsor.

B) Tool Servicing

Despite the improved wear characteristics, a considerable amount of tool servicing is still required to keep a high speed transfer line functioning. As indicated in the previous transfer line floor layouts (Figure 3-18) tool servicing facilities are spotted liberally in the vicinity of the transfer lines. These facilities consist primarily of a tool board such as that illustrated in Figure 3-34.

FIGURE 3-31 DRILL BITS

Condition or result(a)	Conventional point	Modified point
Speed, rpm	71	91
Speed, sfm	51	66
Production, pieces per hour	4.875	5.625
Drill life per grind, pieces	42	84

(a) Both types of drill were used in a radial drill press, at a feed of 0.013 ipr and with a 1-to-20 mixture of soluble oil and water as the cutting fluid.

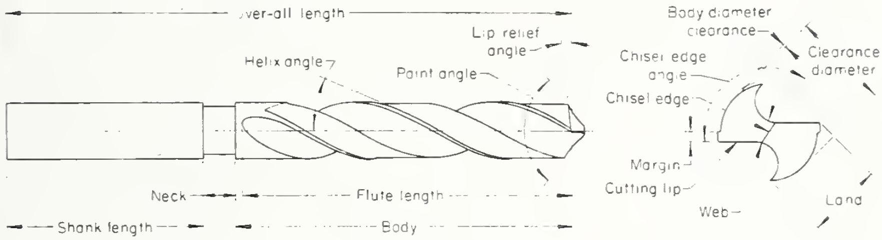


FIGURE 3-32. DESIGN FEATURES OF A TYPICAL STRAIGHT-SHANK TWIST DRILL

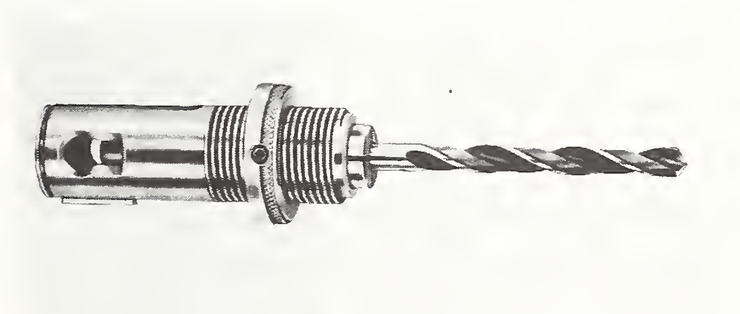


FIGURE 3-33. ADJUSTABLE ADAPTER

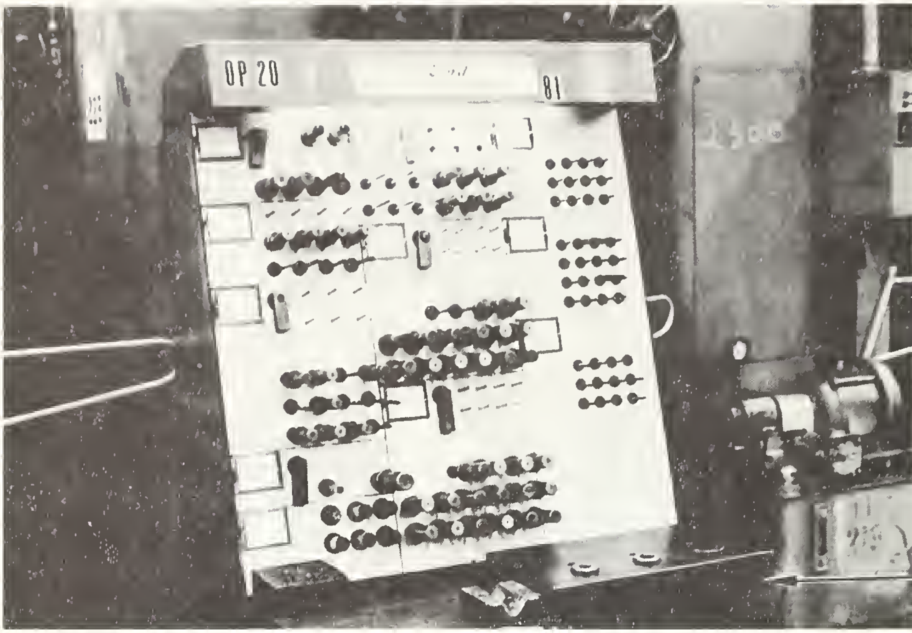


FIGURE 3-34 TOOL BOARD - OPERATION 20, HEAD MACHINING

The boards provide a systematic and convenient arrangement of new or refurbished tools available for immediate installation. The boards are serviced by tool chasers whose primary responsibility is to keep the boards constantly restocked with properly sharpened and gauged cutting tools, and returning the defective tools to maintenance for regrinding and recycling. In order to minimize transfer line downtime, all tool bits are preinstalled in quick release holders or adjustable adapters as illustrated in Figure 3-33. A cutting tool can be changed on the line within seconds. Because the depth of tool cuts vary among spindles, each drill must be positioned at the proper distance within the tool drivers. This is accomplished offline by use of tool gauges. Thus, variations of several inches may be accommodated by the same type of drill within similar type tool holders. As the tools wear under repeated resharpening, the length shortens. Ultimately, when a drill bit becomes too short for its original application, it is assigned to a different drilling operation requiring shorter lengths. Indeed, tool bits are passed on to three or four different operations before they are discarded

Figure 3-35 illustrates more clearly the arrangement of the tool bits, tool drivers, and gauges on the tool board. The identification cards contain the transfer line station number, the hole numbers on the stock being machined as well as a code designation for the drill drivers, adapters and gauges. The card in the illustration identifies the drill bits as being used for cylinder head C on holes 33 through 37 and 69, at station 55-Left on Operation 20C, of the head machining transfer line. The gauge specifies that the tool bit length be 6.077 inches. Another identification card on the same board indicates that a similar type drill is used at station 57-Left for holes 25 through 32 but at a different tool length of 6.23 inches. Each gauge has a specified slot with spare tool bits adjoining. The tool drives shown in the illustration have already been pre-gauged for immediate replacement in the event a tool breaks or the system goes down for the next tool change.

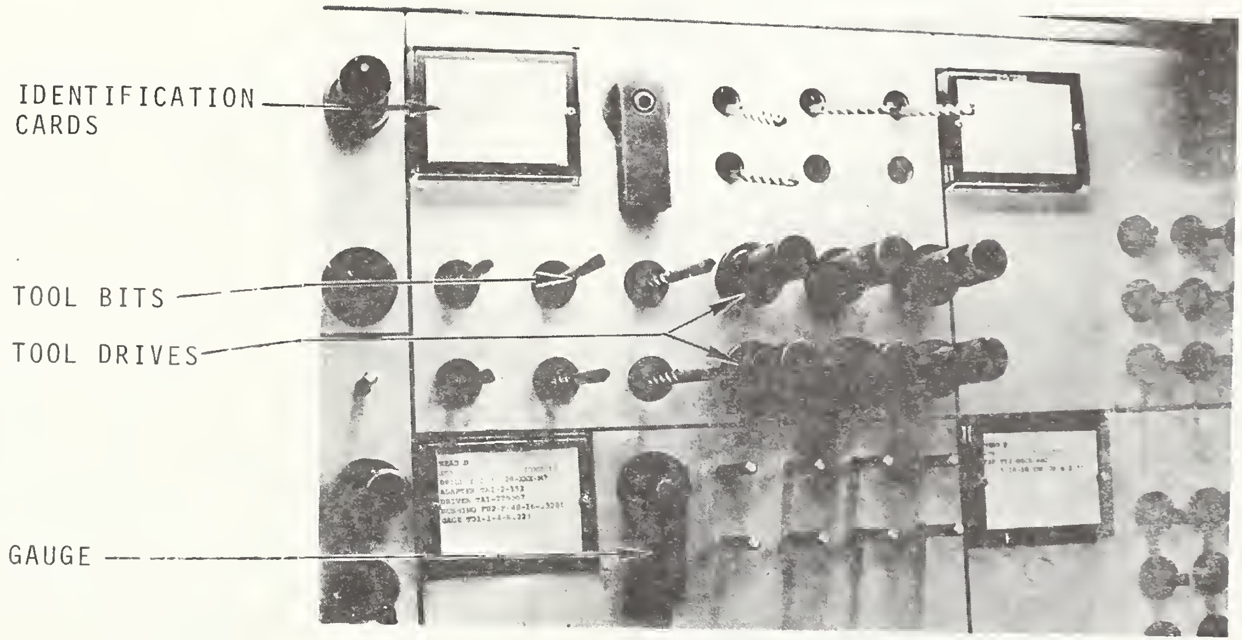


FIGURE 3-35 TOOL BOARD - BITS, DRIVERS AND GAUGES FOR FOUR TYPES OF HEAD

A considerable degree of manufacturing engineering and process is involved behind each tool board set up. Table 3-5 has a listing of typical design and selection criteria associated with the tool boards of Operation 20. This criteria also applies to the design of the transfer line as well as to the specification of the machine tool units at each station. The tool design and selection process requires widely varying degrees of skill and technical knowledge. Some elements of tooling may change little over an extended period of time, while others are constantly undergoing change brought about by frequent small changes to the engine. A major engine change such as downsizing to smaller displacements will require a significant tool design effort.

Continuous inspection of work-in-process through quality control sampling is a further check on effectiveness of tool wear monitoring. Such an inspection would take place at the end of Operation 20C on a cylinder head sample once every hour. Accurate gauges then check the quality of the cutting surface and dimensional accuracy of each of the holes that have been bored.

C) Floats

A float of finished stock at the end of Operation 20C is necessary for tool servicing. Assuming that all cutting bits are replaced at least once a shift, sufficient stock must be available to keep the next transfer line supplied while 20C's down for tool bit replacement. The build up of the stock or float is usually accomplished automatically when one transfer line is down and the other one preceding it continues to produce stock (refer to Figure 3-36). That is, when line 20D goes down the output of line 20C continues to build up work-in-process. When line 20C goes down, the line 20D works off the float that line 20C had previously built up. Line supervisors, as a rule, like to maintain float margins of one hour of production. In general practice, though, as large a float as possible is desirable. Available storage space for some of the larger components such as the engine block may become a limiting factor.

TABLE 3-5. TOOL BOARD - OPERATION 20

ITEMS REQUIRING TECHNICAL EVALUATION AND DECISION FOR EACH TOOL AND EACH CHANGE OF TOOL DESIGN

1) <u>Material Being Machined</u>

- Metallurigical designation and specification
- Hardness - Rockwell/Brinell
- Toughness

2) <u>Hole Being Drilled</u>

- Diameter
- Depth
- Accuracy specifications
- Surface finish specifications
- Straightness requirements

3) <u>Selection of Drill</u>

- Metallurgical specification and heat treatment
- Shape of cutting edge
- Angles of cutting and contact surfaces
- Clearances
- Quality control specifications on drills received from manufuacturer
- Sharpening specifications - material removal; type of sharpening wheel or machine

4) <u>Use of Drill</u>

- Rotational speed
- Depth feed rate
- Cooling material - specification and quantity
- Number of drillings before sharpening
- Condition of drill requiring replacement
- Measurement of drilled holes as a check on drill wear; spot check or continuous

5) <u>Drill Rack</u>

- Number of drill holders for each operation
- Number and design of gauges and checking fixture
- Personnel requirements for maintenance of drill rack in ready condition
- Floor area required for rack and location with respect to drilling machine.

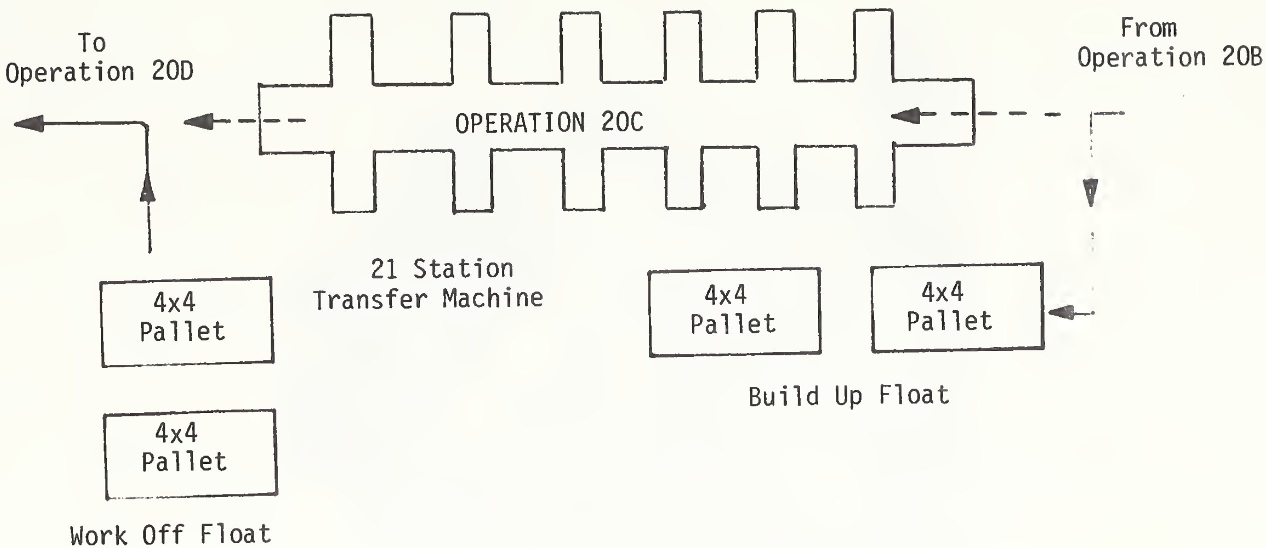


FIGURE 3-36. CYLINDER HEAD MACHINING
FLOAT UTILIZATION DURING DOWNTIME

D) Tool Replacement Scheduling

Efficient scheduling of tool replacement coupled with adequate quantities of float can keep an entire machining line running without interruption. The significance of this can be observed more graphically from Table 3-4 for cylinder block machining involving 20-odd transfer lines and 18 separate floats. It is conceivable that the complete cylinder block machining line could be shut down once a shift for all tool replacement assuming an adequate float stock of finished cylinder blocks had accumulated to feed final engine assembly. By allowing separate floats between each of the transfer line operations, any single transfer line failure or downtime for tool replacement can be accommodated without interfering with the balance of the operation.

E) Typical Transfer Operation

The degree of variation in high speed machining operations may be appreciated by examining parts of it more closely. A good example is the main oil gallery hole of the cylinder block— a primary source of lubrication to the cam shaft. This hole extends the full length of the block, as illustrated in the 351W cutaway, Figure 3-37. It is identified as #212 on the engineering process sketch sheets, as shown in the front and rear views in Figure 3-38 and Figure 3-39. Machining is performed at Operation 70 by Bhur 24-station transfer machine. To accomplish this, Operation 70 performs six basic operations, six passes, bores the right and left sides simultaneously, automatically indexes the blocks to the next operation, and automatically senses and shuts down the system in the event of tool breakage. A layout plan of Operation 70 is shown in Figure 3-40 with the basic operations identified in the accompanying table. Of the six categories specified, four are performed on hole 212 while the remaining two are designed for holes other than 212. The significance of the second column labeled "other" are that other holes of the block receive the same machining operations as specified for hole #212.

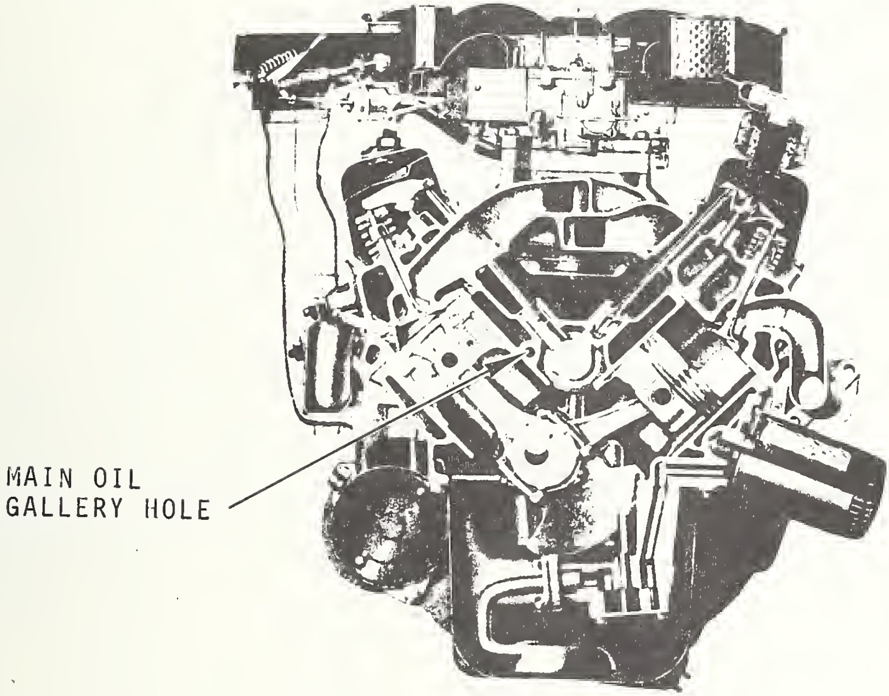


FIGURE 3-37. 351W CUT-AWAY

FORD MOTOR COMPANY OF CANADA LIMITED

WINDSOR MANUFACTURING OPERATIONS PROCESS SKETCH SHEET

MANUFACTURING ENGINEERING DEPARTMENT

PART NO. C905-60 C-B

RELEASE	PART NAME CYLINDER BLOCK	SHEET OF

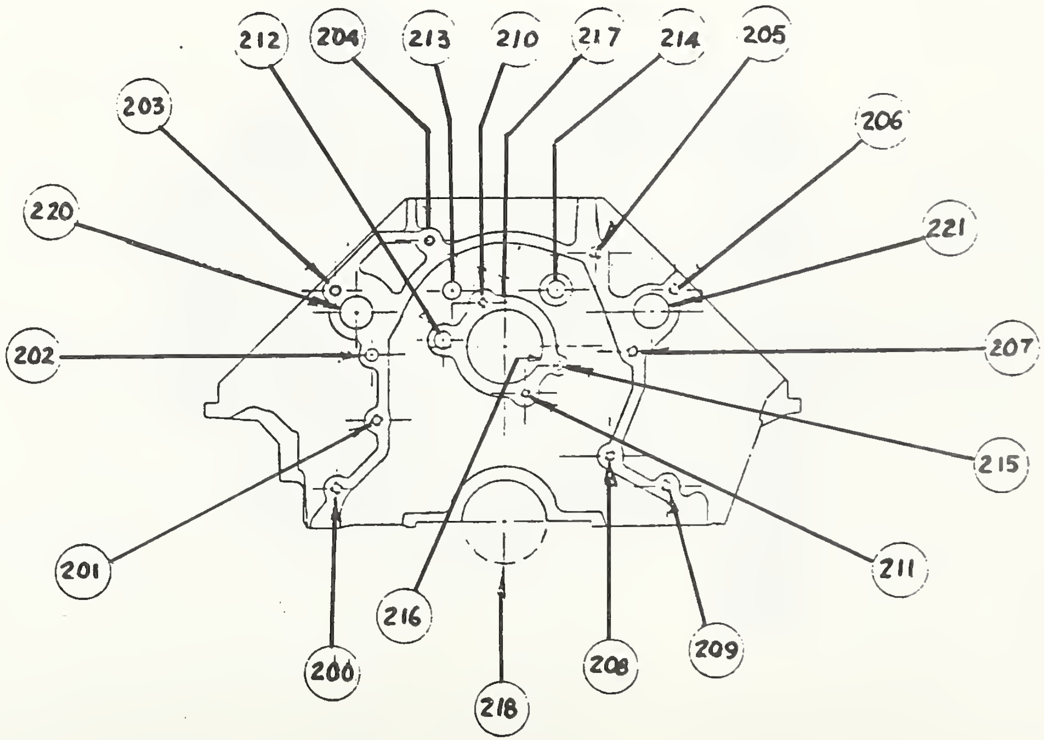


FIGURE 3-38. HOLE CHART FRONT VIEW

FORD MOTOR COMPAN F CANADA LIMITED

WINDSOR MANUFACTURING OPERATIONS PROCESS SKETCH SHEET

MANUFACTURING ENGINEERING DEPARTMENT

PART NO. C9OE-6010-B

RELEASE	PART NAME CYLINDER BLOCK	SHEET OF

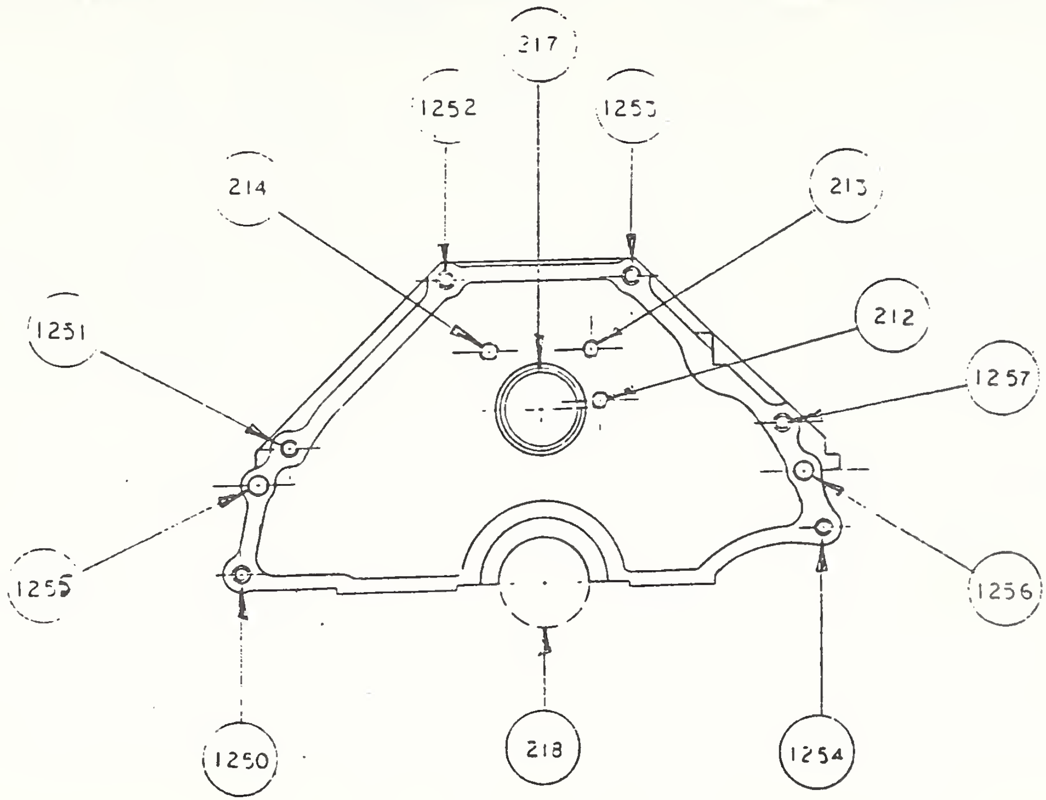
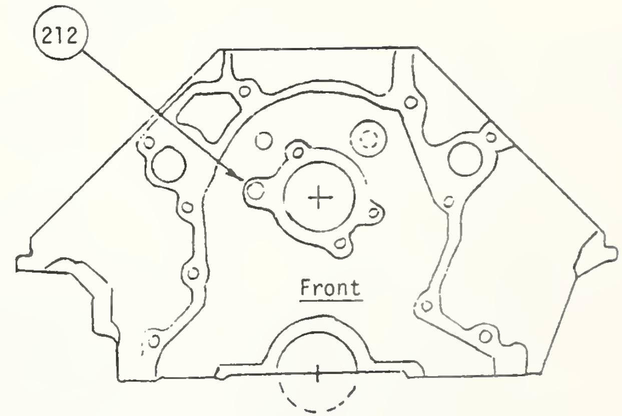


FIGURE 3-39. HOLE CHART REAR VIEW

Basic Operation	Hole 212	Other
(a) Drill (6 Passes)	X	X
(b) Chamfer	X	X
(c) Ream & Counterbore	X	X
(d) Probe & Blow-Out	X	X
(e) Spotface		X
(f) End Mill		X



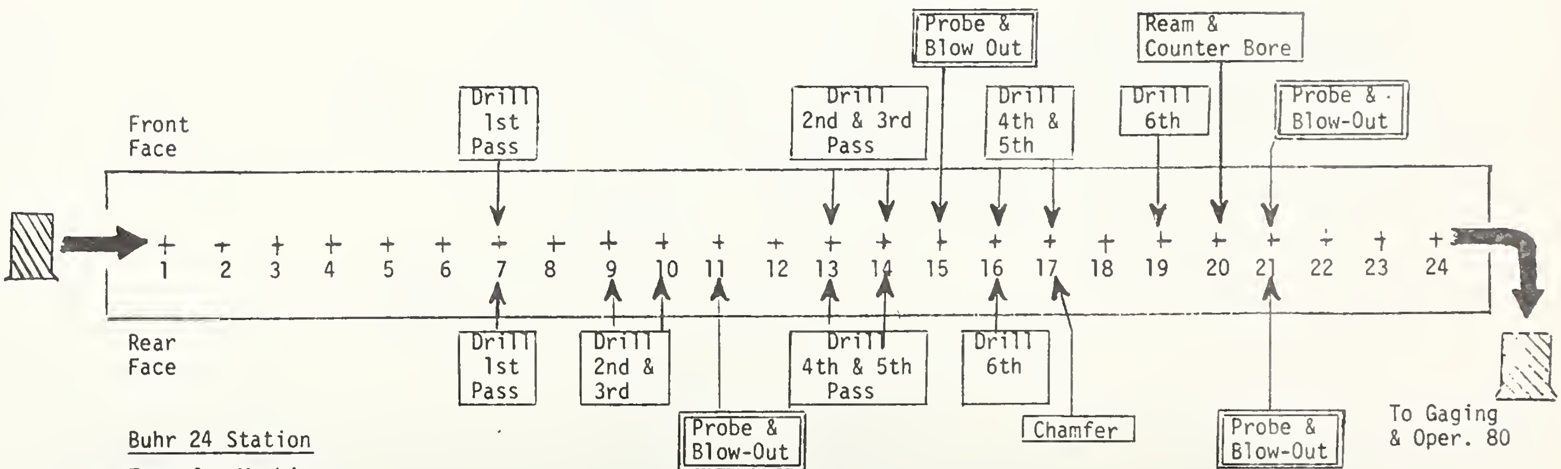


FIGURE 3-40. MACHINE OPERATIONS
MAIN OIL GALLERY HOLE (OPERATION 70)

TABLE 3-6. OPERATION 70 HOLE LISTING

200-209	Cylinder front cover mounting holes
210	Camshaft thrust plate mounting
211	Camshaft thrust plate mounting
213	Tappet oil gallery hole (front and rear)
214	Tappet oil gallery hole (front and rear)
215	Distributor oil
216	Cam to distributor oil
217	Camshaft
218	Crankshaft
220 & 221	Water Pump
1250-1254	Flywheel housing
1255	Flywheel housing dowel hole
1256	Flywheel housing dowel hole

Holes Requiring Three or More Transfer Lines

39	Oil hole - main gallery to crank
40-42	Oil hole - main gallery to crank
43	Oil hole - main gallery to crank
51	Crossover filter to main gallery
54	Filter mounting hole
132	Rear oil drain back
154	Distributor body hole Distributor shaft hole
217	Camshaft hole
218	Camshaft hole
1255	Flywheel housing dowel
1256	Flywheel housing dowel
1257	Flywheel housing dowel
Cylinder Bores	#1 through #8

Referring again to Figure 3-40, the engine blocks enter the line from the left in a transverse position, exposing the front and rear faces to the machine operations on both sides of the line. The first machine operation does not take place until Station 7 where the first of six drilling passes is performed on the front and rear faces of the block. The block is then indexed to Stations 9 and 10 where the second and third drilling pass is performed, but only on the rear face. At Station 11, the rear face hole is probed and cleaned of chipped debris by compressed air. At Stations 13 and 14, the second and third passes are performed on the front face as well as the fourth and fifth pass on the rear face. At Station 15, the front face is probed and blown of chip debris. Drilling operations through the entire length of block is finally completed at Station 19. Final probe and blow out is then performed at both ends of the block.

The distance the stock travels for the single operation of drilling the main gallery hole is approximately 50 feet. However, other operations are performed at this point of the machining process as indicated by the hole number designation in Table 3-6. There are also a number of machining operations which are not completed by Operation 70. The reasons vary as to the need for additional transfer line operations. In some instances, it is a convenient method of balancing out machine tool work load in order to smooth out work-in-process flow. Hole geometry and complexity of required machining is another reason. Certain additonal machining on some surfaces cannot be accomplished until more basic tool cutting is down elsewhere on the block. Hence, these operations must be deferred. As an example, tapping requires a different cutting fluid than that used for cutting metal or drilling. Consequently, all tapping of bolt holes is consolidated at specific transfer lines for that purpose.

A considerable amount of machining is done at Operation 70 in addition to holes 212. Figures 3-38 and 3-39 illustrate all holes for the front and rear face of the block. A composite listing

of these holes and the location of the required machining operations is shown on Figure 3-41. From this matrix, it is observed that Operation 70 contains 24 independent stations, not all of which are assigned machine tool functions. Some stations have quite a number of tooling operations while others only a few. The legend identifies the particular machine tool operation performed while the letters "R" and "L" respectively indicate whether on the right or left hand side of the transfer line. The types of machine tool operations are specified even further by the column heading at the bottom of the chart.

From a total holes count and the type of machine operation performed at a particular station, the level of complexity can be judged. For example, at Station 16, holes 200 through 209 and hole 211 on the left hand side of the transfer line are chamfered while holes 212, 213, and 214 front and rear face are drilled. The number of spindles and geometrical spacing on the drive head can be visualized from the hole charts of Figures 3-38 and 3-39. The right hand head stock contains three spindles in this particular case, while the left hand unit contains 14. Quantities of spindles per individual tool head run from 1 to a high of 17 at Station 15. At a line speed of approximately 65 blocks per hour, individual machine cycle time per station averages out to be about 30 seconds. Within this interval approximately 136 spindles are engaged.

It was mentioned previously that not all stations are active for a given transfer line operation. A primary reason is that there is not sufficient room for power tool units at every location. The complexity and quantity of spindles and the size of the head stock is another variable affecting position assignment. Some minimal spacing is also needed for tool changing and servicing.

Transfer line reliability also enters into the question. Overly complex or dense transfer lines can cause an imbalance of servicing downtime. Each line also has catastrophic failure safeguards. Tool breakage occasionally occurs midway through a cutting cycle, requiring immediate shutdown. The probe and blow out operations are designed to mitigate these occurances and are

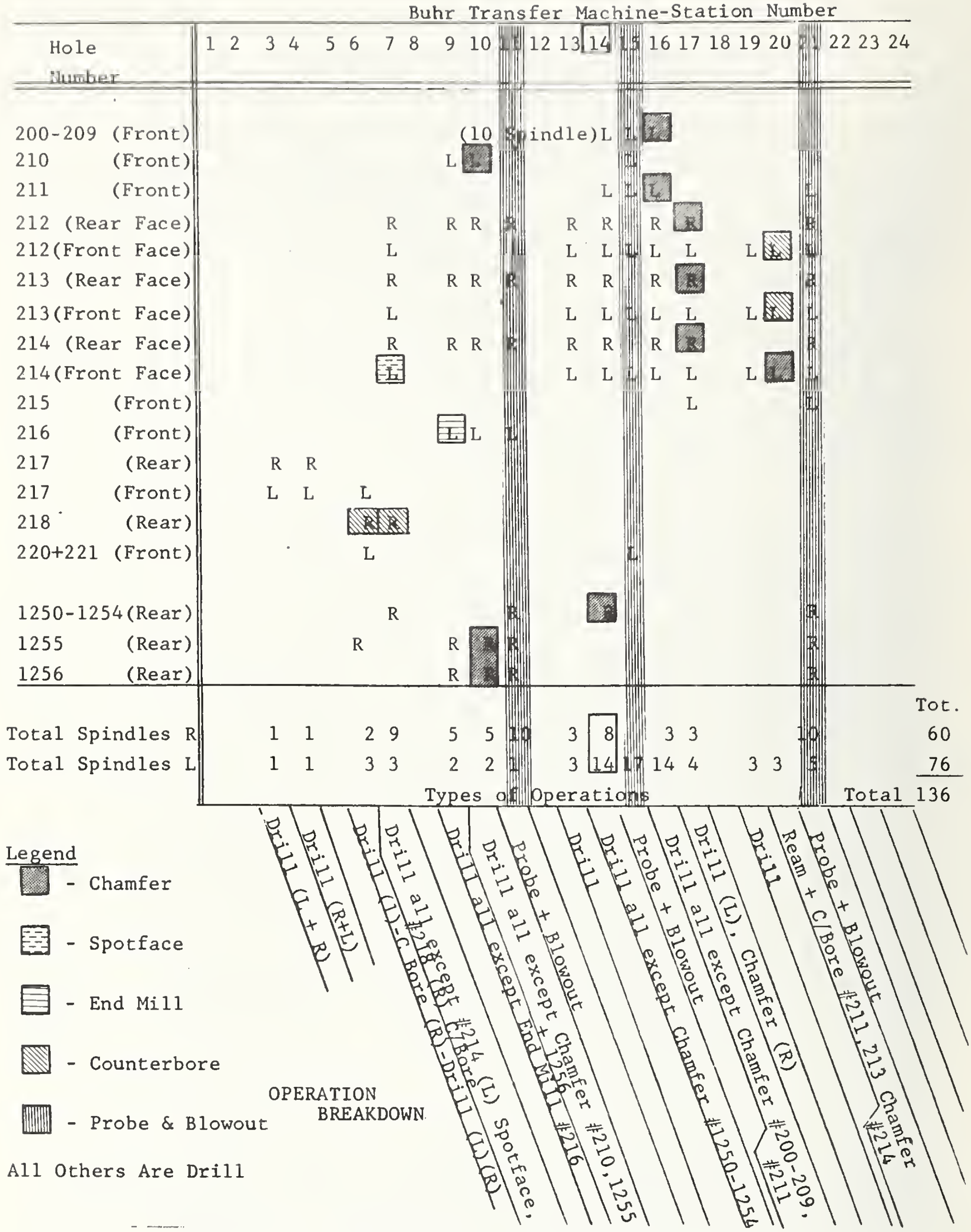


FIGURE 3-41. OPERATION 70 - MACHINE TOOL MATRIX

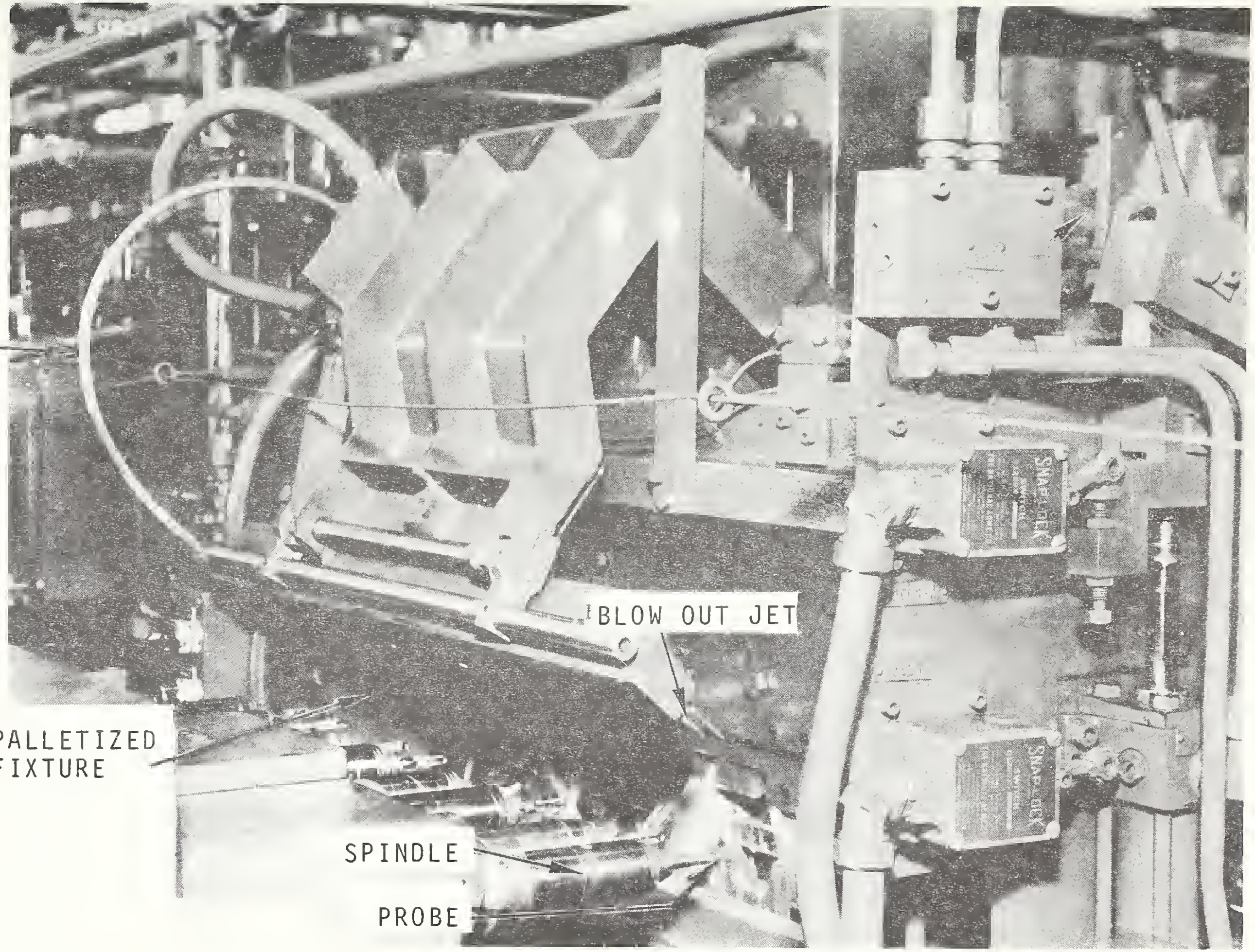


FIGURE 3-42 PROBE AND BLOW OUT TOOL BREAKAGE SENSING

used as often as necessary in those applications where large quantities of metal are removed or excess strain on the tool cutting bits develops. A typical probe and blow out unit is shown in Figure 3-41. The spindle and tool holder are very similar to that used for drilling. Separate blow out jets are inserted into the holes to clean out the debris. Referring back to Figure 3-41, note that a particular machine tool unit may have a mix of tooling operations. For example, at Station 20, a left hand unit performs both chamfering and counter bore while over at Station 10, we have a combination of chamfering and drilling. The specialization of probe and blow out seems to make this a captive activity at Stations 11, 15, and 21.

3.4.7 Summary

This section described in some detail basic principles of machine tool operation. Only one or two of the major operations has been discussed; however, these are representative of high capacity, modern automotive machine tool systems. Of importance to note is that the system is based on a large volume of a repetitive but complex machining operations. Because of precision tolerances requirements in addition to volume production, large manufacturing capital costs are involved. Except over a very limited range, little flexibility is inherent in the system to accommodate change. Only a single product is made with very limited or minor variations, but under a manufacturing environment that is engineered to turn out the product in large quantities at minimum cost. Today's productivity at Windsor Plant No. 1 is the result of small continuous improvements in manufacturing operations since the plant was first designed for volume engine production in 1965. Engine manufacturing operations, therefore, differ from some other areas of automotive manufacturing where tooling must accommodate more frequent product changes.

3.5 REFERENCES

Figure	Photo Credit
3-9	Cross-Fraser
3-10	F. Jos. Lamb Co.
3-11, 3-12	Greenlee Bros. & Co.
3-13, 3-14 3-19 through 3-29 3-31	T. Taylor, Corporate-Tech Planning Inc.
3-32	ASM Committee on Drilling and Reaming, "Drilling," <u>Metals Handbook</u>, <u>Machining</u>, Vol. 3, 8th Edition, Lymat, T., Editor, American Society for Metals, 1967, P. 78.
3-33	Bendix Industrial Tools Division
3-34, 3-35	T. Taylor
3-37	Ford Motor Company
3-42	Greenlee Bros. & Co.

4. MANUFACTURING COST AND PRODUCT CHANGES

The high production volumes required in engine manufacturing dictate large plant investments, major portions of which are attributed to specialized machine tool operations. Demands on automation for increased throughput and shorter machine cycle time, as well as the necessity of maintaining close cutting tolerances, incur large capital costs. Consequently, any product change to the engine is carefully reviewed towards its impact on tooling. The machine tooling industry itself is heavily competitive which tends to keep costs in line. The tooling industry has accomplished this in part by reducing its own engineering overhead to 15% [1] of the product cost. Commonality of machine tool design was a major contributor along with systems engineering techniques that use building block principles to provide a complete machining operation from start to finish. An independent supplier has often been engaged by auto manufacturers to design, deliver, and test a complete machine tool system for a major engine component such as cylinder block or head. The contractor, in turn, often subcontracts out to other suppliers for those facilities in which he himself does not make or design. However, he is responsible for integrating the entire manufacturing package on a turnkey basis. The F. Joseph Lamb Company who specializes in cylinder head machining delivered 14 transfer line systems for Ford's 4-cylinder engine plant in Dagenham, England. The A. T. Cross Company has done similar work in the 4 and 8 cylinder engine block lines. The following are typical of machine tooling costs:*

4-cylinder block line (all new) - $16 million [2]
V-8 cylinder block line (all new) - $20 million [2]

A 20 station in-line transfer line of which 12 stations contain machine tool production units (i.e., drill, ream, counter bore and tap) - $1.2 million. [2]

*Costs cover plant expenditures only and are exclusive of engineering of product changes, R&D, and support performed outside of the engine plant.

Individual machine tool station cost:

Boring	$200,000[2]
Drilling and tapping	$100,000[2]
20 spindle tool head such as described in Section 3.3	$ 25,000[3]

Tool heads for drilling operations may run from $15,000 to $300,000 depending upon complexity and capacity.[1]

4.1 COST OF PRODUCT CHANGES

The effect on manufacturing cost due to engine product changes may be classified at four different levels. The least costly changes are those due to year to year model improvements, involving small parts and little change to the manufacturing process. Included in this category are improved cylinder head valve seals, and retainers or perhaps a stamped versus a forged rocker arm. The reasons for such changes are often due to cost reduction of the product itself, as well as to regulatory action stemming from emissions, weight reduction, and fuel economy. Cost impact on tooling are in the $2 - $3 million range.

Higher levels of cost are incurred in a change of a complete subassembly. Use of aluminum instead of steel for intake manifolds or engine front covers in order to achieve weight reduction is an example of this category. Another was the need to case harden valve seats due to the use of non-leaded gasoline. These cost changes run in the $25 million range.

A third class with a significantly higher impact on cost would be a major change to the overall engine, such as completely all new engine or a smaller engine that has been downsized off a larger block. Changes of this category can impact the tooling on all of the machining lines with investment costs running from $150 million to $250 million.

The fourth or highest cost category are those associated with the building of an all new plant which includes brick and mortar in addition to all new machine tool operations. Typical of today's figures are the $533 million for a 1.3 million square foot facility for Ford's new V-6 engine plant in Windsor, Ontario. $200 million (4)

of this cost is for tooling alone. This facility will employ approximately 2,600 with production starting sometime in April 1981.

The foregoing categories or classes of cost cover plant expenditures only. All of the engineering associated with design of product changes, the research and development costs, and all other support costs incurred outside of the engine plant are not included in these values. Manufacturing costs cover only that necessary to produce the product after the design and engineering work have been completed. On the surface, it may seem hard to understand why some costs are as high as they are. It would appear, for example, that downsizing an engine to a smaller displacement but using the same engine block would have relatively minor cost impact on machine tooling. A closer examination of the changes involved indicates differently:

1) The cylinder block bore is downsized to one of a smaller diameter.

2) The cylinder head is modified to allow for the smaller combustion chamber thus requiring a new casting.

3) A new piston size is required to fit the smaller bore of the block. The smaller piston requires a modification of the piston pin and/or crank shaft to compensate for change in balance.

4) Other areas affected may include valves and push rods, and main bearing surfaces.

As a consequence, tooling changes are required to the cylinder block, cylinder head, crank shaft and piston machining lines. The plant lay-out of the machine tool operations, however, remains basically the same.

Other changes such as new electronic engine controls (EEC) using feed-back controlled carburetion or new emission control devices will have greater effect on final engine assembly. Calibration, test procedures and equipment in final engine tests are particularly affected by this kind of a change. Substitution of new material such as aluminum instead of a steel for intake manifolds or cylinder

heads requires completely new tooling from the floor up. Aluminum requires different cutting speeds. It also requires faster chip removal and disposal. Porosity testing of some aluminum components such as engine front covers are required to check for leaks. A slight change to an engine block's geometrical dimensions has a major impact on the line automation itself. A V-6 engine block in place of a V-8 requires redimensioning all guide ways on transfer line automation. With over a thousand feet of cylinder block line automation, the cost of change becomes significant.

4.2 PRODUCT CHANGE EXAMPLES

A look at several of these product changes in greater detail shows more specifically how the manufacturing process and machine tooling are affected. Three classes of the changes discussed above are 1) PCR or the Product Change Request, 2) a subassembly change, and 3) an all new engine change. Examples of the PCR and subassembly changes which were incorporated into the 351W engine are identified on Figure 4-1. The single beaded valve key, rotating retainer, nylon oil seal, and the stamped rocker arm and stud are PCR type changes, while the aluminum manifold and front cover as well as valve seat hardening are classified as type 2, subassembly changes.

4.2.1 <u>Class 1 - Product Change Request (PCR's)</u>

The change to the cylinder head valve retainer, key and seal, is typical of the type of product change resulting from higher emission standards and the need to use non-leaded gasoline. The purpose of this change was to mechanize valve rotation in conjunction with the valve seat hardening and to reduce hydrocarbon emissions. This change resulted in modifications to three areas of the valve assembly:

A. Valve retainer was changed from a straight to a rotating type.

B. The valve key went from a 4 bead to a single bead.

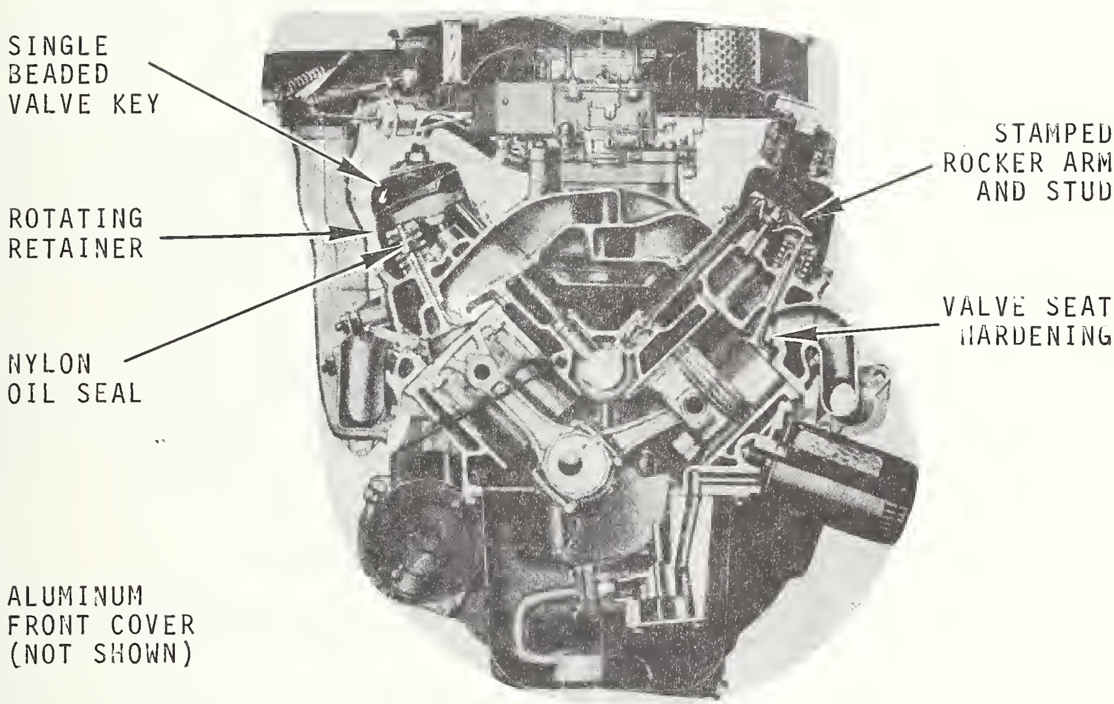


FIGURE 4-1. 351W PRODUCT CHANGES

C. The oil seal was changed from rubber to nylon.

The valve parts affected by the change are illustrated in Figure 4-2. Valve rotation is achieved by mechanical motion of the valve retainer. Spring loaded steel balls in conjunction with an inclined surface of the retainer causes the valve to rotate 90^{o} at each stroke. In conjunction with the hardened valve seats, the 90^{o} rotation counteracts uneven wear resulting in improved wear characteristics.

By changing the oil seal from rubber to nylon, oil leakage past the valve stem into the exhaust manifold was reduced which in turn reduced hydrocarbon emissions. The change of the valve key from four beads to a single bead (shown in Figure 4-3) was done primarily to reduce manufacturing costs.

A stamped instead of a forged rocker arm, is another change instituted more as a cost reduction and not necessarily related to emission or fuel economy requirements. This change, instituted in the 1977 model year, consisted of:

A. Going from a 3 to a 2 piece assembly;

B. Making the oil splash deflector an integral part of the stamping;

C. Use of a threaded bolt instead of a press fitted stud on the rocker arm fulcrum seat.

The original installation of this assembly is shown in Figure 4-4 while comparative views of the new stamped versus the originally forged rocker arms are shown in Figure 4-5.

As minor as the rocker arm change may appear, its impact on the manufacturing process was somewhat involved. A major area affected was cylinder head machining. This required tooling changes in areas of chamfering and drilling for 8 rocker arm bolt holes as indicated by holes number 25 through 32 on the manufacturing process drawing (Figure 4-6). The transfer line operation performing this are the left hand sides at Stations #7 and #8, Operation 20A. Because cylinder head machining is performed on two identical

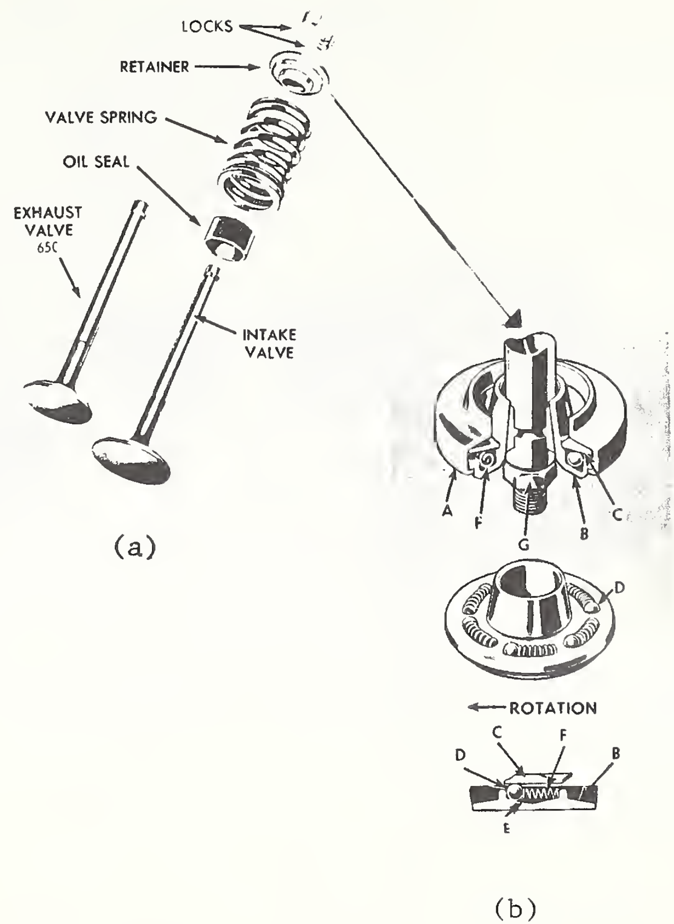


FIGURE 4-2. CYLINDER HEAD VALVE ASSEMBLY

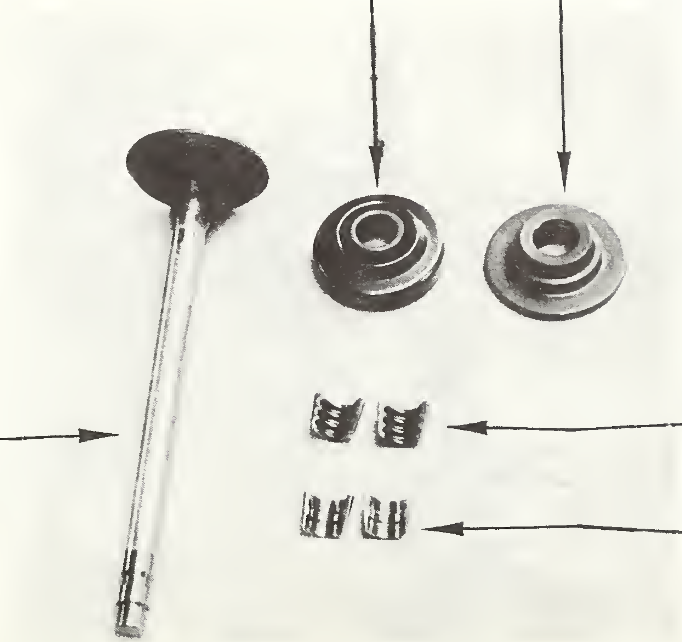


FIGURE 4-3 VALVE ASSEMBLY

Valve Rocker Arm

(a)

(b)

FIGURE 4-4. ROCKER ARM ASSEMBLY AND INSTALLATION

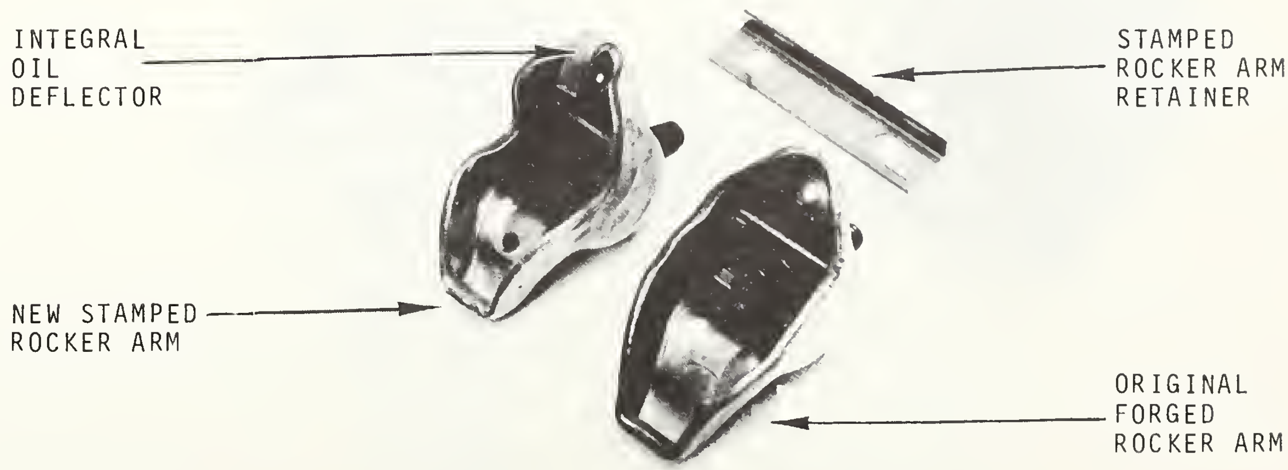


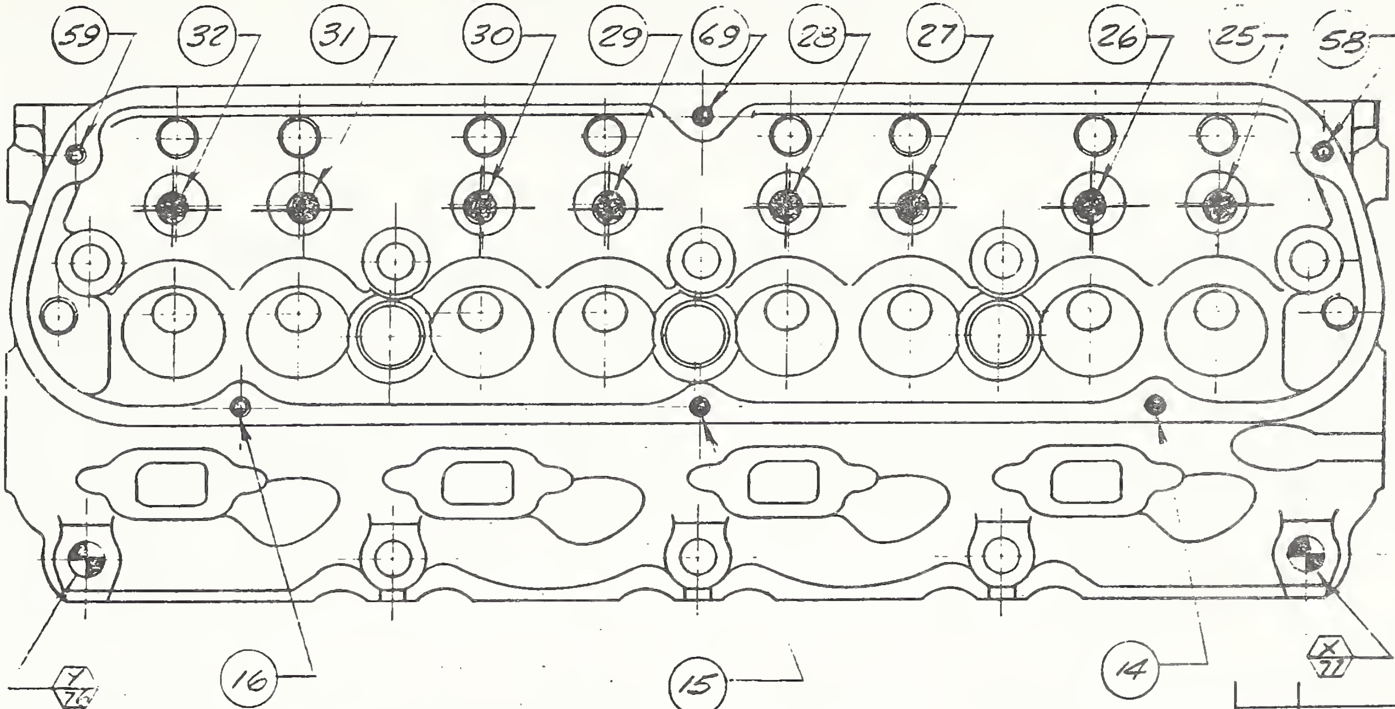
FIGURE 4-5 ROCKER ARM

FORD MOTOR COMPANY OF CANADA LIMITED
WINDSOR MANUFACTURING OPERATIONS PROCESS SKETCH SHEET
MANUFACTURING ENGINEERING DEPARTMENT

PART NO. 6C7C.

RELEASE | PART NAME CYLINDER HEAD | SHEET OF

STATION #7 & 8 L.H.



LOCATION "X" & "Y" HOLES #76 & #77

A. STA #7 L.H. CHAMFER (6) COVER MTG HOLES #14-15-16-58-59 & 69
CHAMFER (8) ROCKER ARM BOLT HOLES #25 THRU #32

B. STA #8 L.H. DRILL (6) COVER MTG HOLES #14-15-16-58-59 & 69
DRILL (8) ROCKER ARM HOLES #25 THRU #32

PROCESS ENGR. MANSON	ISSUE DATE 8-2-77
OPER. 20A	SHEET 10A OF
STATION 7 & 8 L.H.	
	DATE / CHANGE

PART NO. 6049

FIGURE 4-6.- CYLINDER HEAD PROCESS SHEET

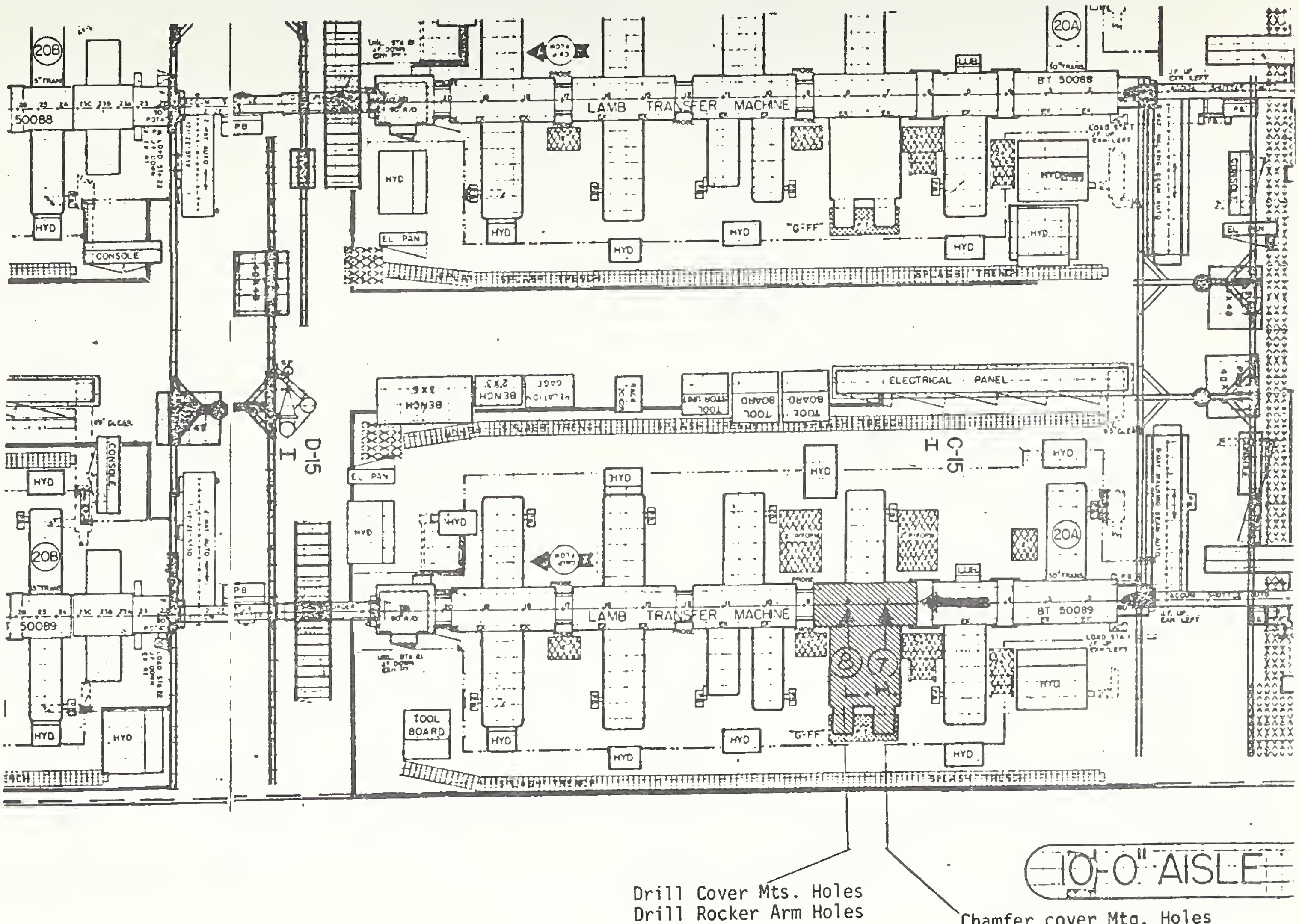
parallel lines (reference Figure 4-7), machine tool changes were required on both the north and south lines.

Other changes to the manufacturing process were also involved as illustrated in Table 4-1. Affected areas include engine assembly as well as tool wing bases, heads, fixtures, etc.

Under tools, new drill bits had to be specified for Stations 7 and 8, and taps for Station 61 of Operation 20C. Because of changes in hole center geometry the orientation of the machine tool production unit in reference to the transfer line and stock positioning had to be modified, requiring an all new base. All new feed units for Stations 7 and 8 were also required because of changes in cut and depth of drilling. The tool and spindle heads also were changed at both Stations 7 and 8 as well as installation of new tap heads at Station 61 in Operation 20C. New fixtures were also required to accommodate new tool bit length and for performing rework in the repair area at Operation 150. New tool bits in turn required a new set of audit gauges. New probes were also required for hole blow out after drilling at Stations 9 and 62 of Operation 20C. Finally, the tool boards containing the replacement tool bits had to be modified to reflect new code designations and locations.

A better view of the precise location of these changes on the cylinder head machining line is illustrated in Figure 4-8. In this illustration, the complete manufacturing process from rough casting to a completed cylinder head assembly are summarized showing sequence and relative positions of each operation on the manufacturing floor. Tooling and facility changes listed in Table 4-1 are indicated by shading. Most of the changes affect the drilling operations performed on the parallel lines of Operation 20.

The above changes are typical PCR's at Ford and cost in the range of 2 to 3 million dollars per year. In the case of rocker arm change, the tooling cost is more than offset by material savings in going from a 3 to a 2 piece part and simplification in the assembly process. The cylinder head valve modification which was due to emission and fuel economy requirements, are costs which are not recovered except by increasing the base price of the automobile.



(Example of impact of Rocker Arm Change on Machining)

FIGURE 4-7. OPERATION 20A - SPECIAL "LAMB" IN-LINE TRANSFER MACHINE

TABLE 4-1. STAMPED ROCKER ARM TOOLING CHANGES

Operation	Wing Bases	Mech. Feed	Heads	Tools	Fixtures	Gauges	Probes	Misc.
Engine Assembly				New 4-Spindle Nut Runner		New (Audit)		
Cylinder Head Machining						New Master Cylinder Head		Tool Boards
Operation 20A Station 7 & 8	New	New (4)	New (4)	New	New (4)	New		Rework
Station 9							New	
Operation 20C Station 61			New	New	Rework	New		Rework
Station 62							New	
Operation 150R					Rework			

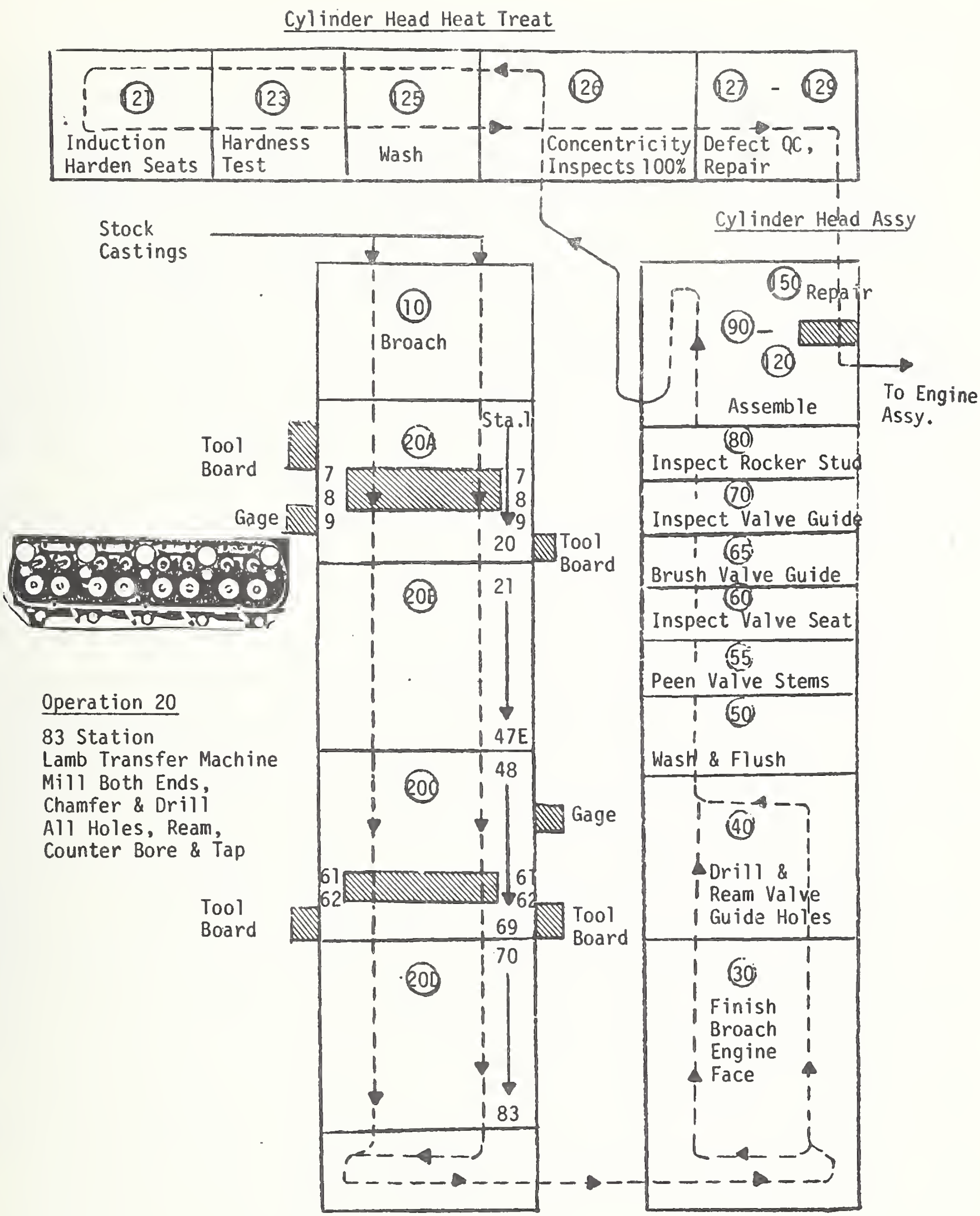


FIGURE 4-8. CYLINDER HEAD TOOLING CHANGE

4.2.2 Class 2 - Subsassembly Changes

At a significantly higher level of cost for manufacturing and retooling are changes to a complete engine subassembly. Three such changes include the aluminum intake manifold and engine front covers, induction hardening of engine head valve seats, and a multiplicity of engine control devices such as vacuum thermiomic switches, EGR valves, positive crankcase ventilation (PCV), air pumps, etc.

As part of Ford's overall fuel economy downsizing program, a number of engine assemblies were redesigned to use substitute lighterweight materials. The use of aluminum for the intake manifolds and engine front covers are typical examples. By substituting aluminum for steel the intake manifold weight was reduced by 30 pounds. The 351 engine in Plant No. 1 will receive the new manifold in 1979 model year along with the engine front cover. Aluminum manifolds will also be used for the new downsized 255 CID Engine in the Spring of 1979 for the 1980 model year. In order to manufacture sufficient quantities of the intake manifolds and engine front covers to meet the combined production needs of the 351 engine and the new 255 in Plant No. 2, an additional 44,000 square feet of component manufacturing area had to be constructed. This facility is located adjacent to Plant No. 1 as illustrated in Figure 4-9.

The induction hardening of cylinder head valve seats as a consequence of non-leaded gasoline was a major manufacturing change instituted in the 1974 model year and resulted in increasing the length of cylinder head machining by 20%. The heat treating process added seven new machine operations (Operation 121 through Operation 129) which were placed at right angles to one end of the two original transfer lines. Initially, these operations consisted of the induction hardening of the seats followed by a hardness test and then a wash. The high temperatures required for hardening resulted in deformation of the original seat tolerances obtained during machining. As a result, additional stations or operations were added after heat treating to permit 100% inspection for concentricity. Those cylinder heads failing inspection were subsequently repaired at Station 129. The cost of this change was well

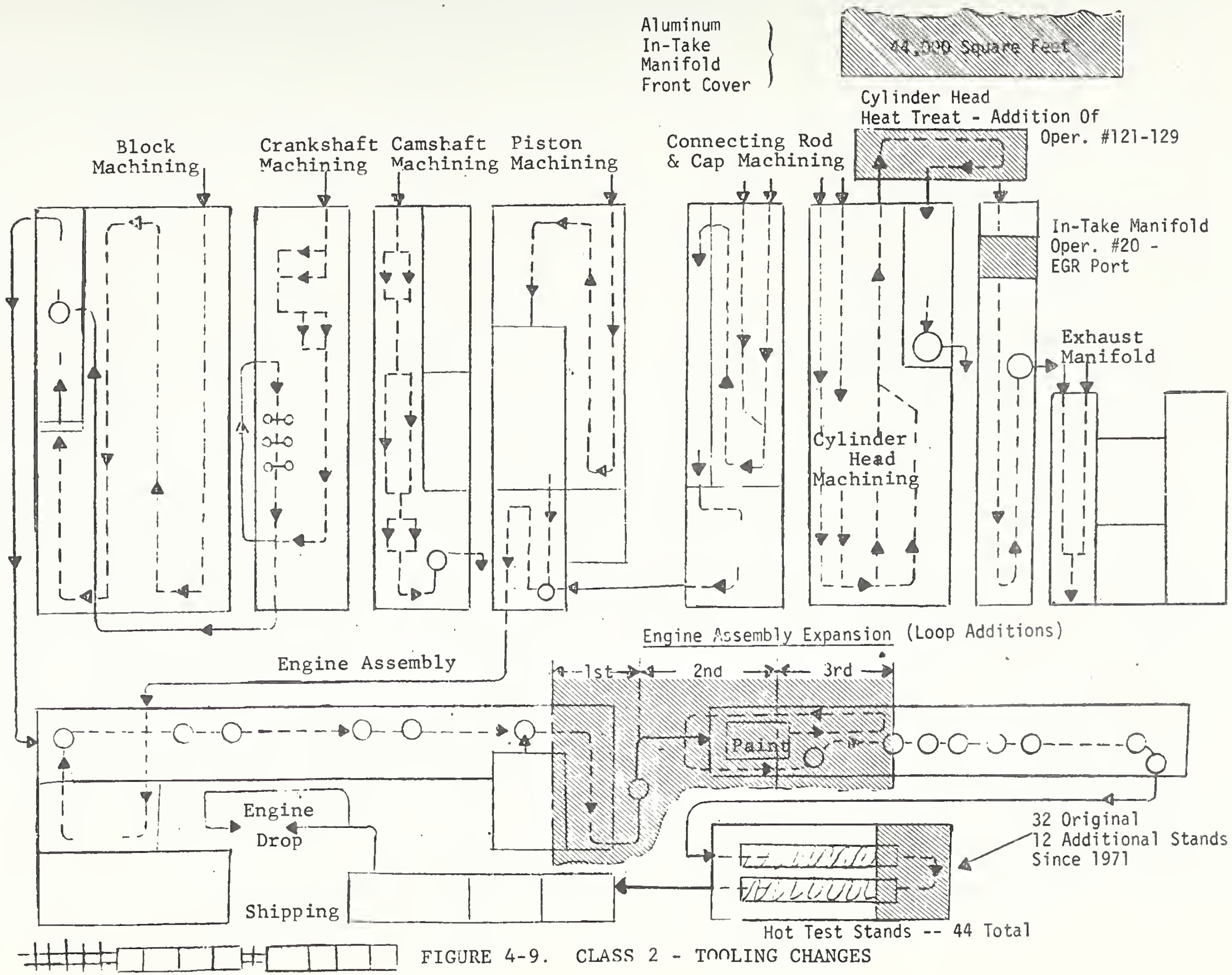


FIGURE 4-9. CLASS 2 - TOOLING CHANGES

in excess of $6 million while costs of other subassembly changes such as the addition of manufacturing space for aluminum intake manifolds, run as high as $25 million.

In the same class as subassembly changes are the modifications and additions to the engine for emission control devices. These devices, principally needed to meet the higher regulatory emission standards, had a heavy impact on final engine assembly as well as engine hot test. Vacuum thermiomic switches, EGR valves, positive crank case ventilation (PCV), and air pump are primarily exterior attachments to the engine proper. The EGR valve did require new parts causing some changes to boring and tapping of Operation 20 of Intake Manifold Machining.

The major problems caused by these changes were finding enough room on the line for the component installation. As a consequence, the engine assembly-line underwent three extensions since 1970. Even with this, space shortages still remain resulting in increased complexity of the existing assembly stations as well as crowding of assembly labor. With space limitations not a factor, additions or changes to engine final assembly-lines are more easily accommodated than changes to a machine transfer line. Assembly-line automation is provided by overhead conveyor systems which are not as costly an implacement as a concrete based guide-ways used in the machining operation. Emission control devices increased Plant #1's assembly-line length by 30% which was achieved by adding U-loops to the conveyor system. The U-loop additions could not interfere with a number of permanent installations or "monuments" whose removal would be prohibitively expensive. A notable example was the engine paint booth which is located 2/3 into the engine assembly process. This facility caused the addition of a number of unnecessary loops to the final assembly conveyor system in order to preserve the paint booth's sequence in the assembly process.

Another area heavily affected by the addition of the emission control devices was engine hot test which caused an increase in length of the hot test procedure. The original test stands were installed in 1971 and increased in number from 32 to 44 at a rate

of 2 per year to keep pace with increased emission test requirements.

A general overview of the impact of the class 2 subassembly changes on Plant #1 manufacturing is also illustrated in Figure 4-9. The shading denotes the transfer lines and engine assembly areas affected. The addition of a cylinder head heat treating transfer line ended up in an area that was formerly stock storage. Engine assembly expansion was accommodated by three successive loop additions without changing the location of the paint booth. The engine hot test stand additions were accommodated by stretching out the 180° loop in the middle of the hot test area.

4.2.3 Class 3 - Major Engine Changes

Any change that involves an all new design or completely different engine such as a V-6 in place of a V-8, or an engine that has changed significantly in size, is considered a major change. Although no such changes are currently planned at Windsor Plant #1, Engine Plant #2 is being retooled for a new small V-8 for the 1980 model year. The plant was originally tooled to produce the 400 CID V-8 and recently was turning out the 351M version of the V-8's. The new engine scheduled for the 1980 model year will be a 255 CID downsized off the 302 CID block. This will require a major retooling of all engine lines; but no change to the original plant lay-out or its conveyor systems. Although the 255 is still a V-8, its overall size and geometry, and critical dimensions are significantly different from the larger 351M and the 400 CID engines. The smaller engine also has different hole diameter spacing as well as changes in bore diameter and crank shaft centers. Each machine tool unit, therefore, must be redesigned to accommodate new mounting positions relative to the plane of the transfer line as well as the orientation and depth of each individual tool cut. In some instances, the original tool feed distances set up for the larger 351 and 400 engines are still within the range of the requirements of a smaller engine, requiring only a change to tool heads. In most other cases complete new tool feeds, power drives, and supporting beds are necessary.

The total retooling effort for Plant No. 2 was divided into three classes of change. One class was those types of changes that could be accommodated on site. Such changes involved new tool heads but retained the original power drive, feed units, and bases. A second class of change involved removal of the complete machine tool production unit from its location and returning it to the vendors' facility for major retrofit. The third class of change and the most comprehensive involved a complete retooling and all new transfer line from the ground up. This included removal of the original machine tool units, removal of transfer line and foundations, and the design and installation of a completely new system.

The degree that each of these three classes of changes were required of the major engine components machining areas is illustrated in Table 4-2. The specific machining requirements of each individual major component determined the amount of tool change required. As an example, the change to drilling and chamfering of Operation 70 for the cylinder block involves new drill bits and a different spindle head; consequently, it can be accommodated on site. Operation 10, on the other hand, involves a broach on the main cylinder block faces. Because of the significant dimensional differences of the smaller block versus the original larger 351 engine, a completely new broaching machine had to be designed. The functions of other operations on cylinder block machining dictates that a large proportion of the tooling had to be completely replaced. Cylinder head machining requirements are similar. On the other hand, the majority of retooling changes for the other engine assemblies may be accommodated on site.

A general overview of the Windsor Plant #2 retooling is shown in Figure 4-10. The three classes of retooling taking place are identified by their respective shadings. It may be observed that Plant #2 has a slightly different layout than that of Plant #1. A major difference is attributed to the location of the short block assembly which is more optimumly positioned

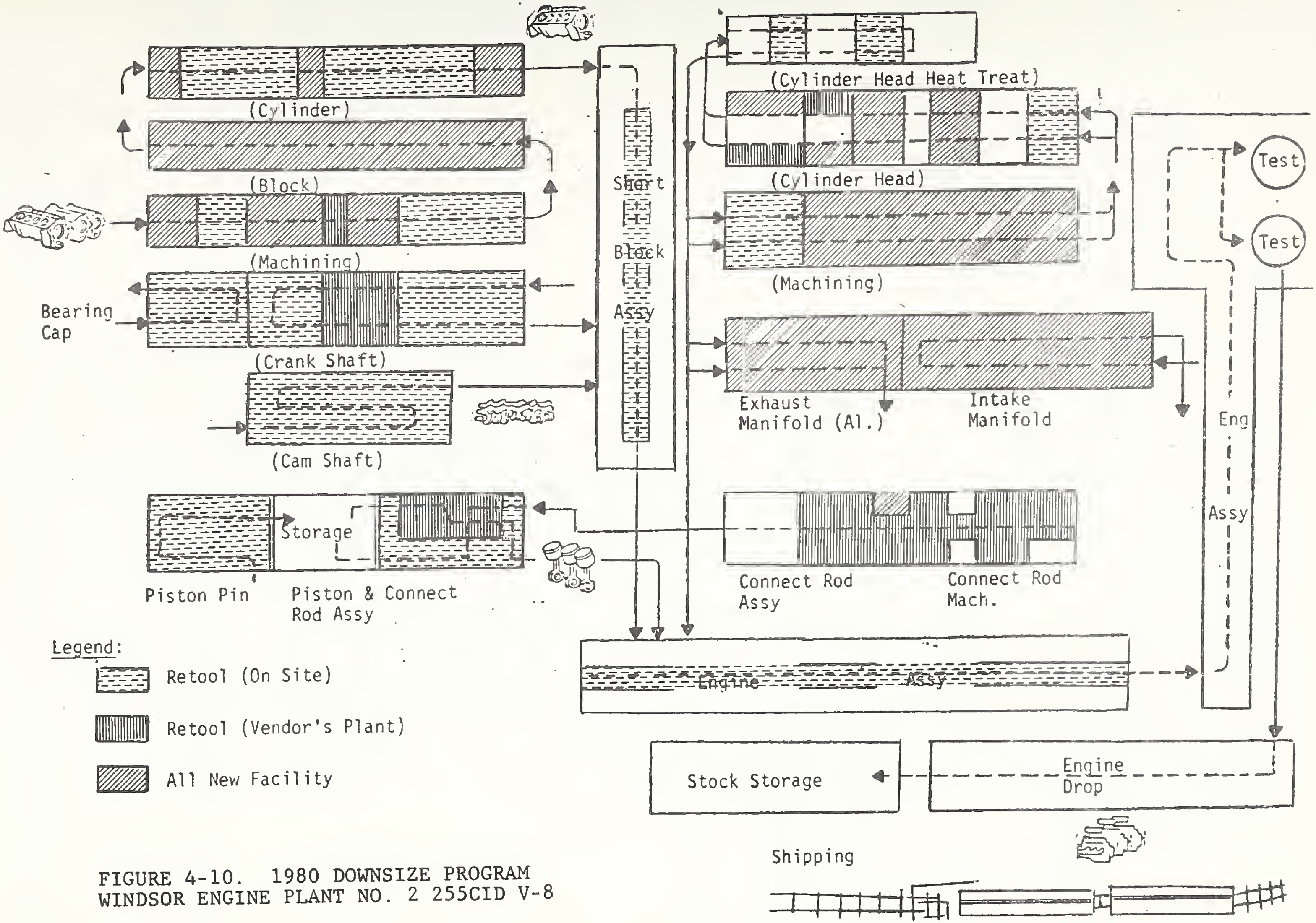


FIGURE 4-10. 1980 DOWNSIZE PROGRAM
WINDSOR ENGINE PLANT NO. 2 255CID V-8

TABLE 4-2. WINDSOR #2 - 255 CID RE-TOOLING

Operations	Re-tool * on site	Re-Tool * at Vendor	Replace Complete all new*
Cylinder Block Machining**	20, 60, 65, 70, 140, 150, 160, 170, 180, 195R	40 231R(2)	10, 30, 35, 50, 80, 90 95, 100, 110, 120, 130, 155, 190(2), 200, 210, 220, 230.
Short Block Assembly	240(washer) Line automation		
Main Bearing Cap	10, 20, 30		
Crankshaft	10, 20, 30(2), 40(2), 70, 75, 80(4), 100(10), 130, 180(2), 190, 200.	50, 50A, 150(4), 210(2).	
Camshaft	20, 60, 80, 100(14), 110(3), 140, 160.		
Piston and Pin Assembly	20(2), 30(4), 40(2), 50(4), 60, 90, Grader		
Piston and Connecting Rod Assembly	20, 30(2), 100(4), 110(4).	80(4)	

*Numbers in parenthesis refer to quantity of parallel operations affected.
**See Appendix A for comparable description of each operation.

TABLE 4-2. WINDSOR #2 - 255 CID RE-TOOLING (CONTINUED)

Operations	Re-tool on site	Re-tool at Vendor	Replace Complete all new*
Cylinder Head Machining	10(2), 30(2), 121, 125, 129R	110(2), 50R	20A(2), 20B(2), 20C(2), 20D(2), 40(2), 50, 70, 80, 90.
Cylinder Head Assembly	Coroma Repair	150R	Seal Assembly, Valve Assembly - 10, Valve Keeper, Dowel Assembly, Radial Drill Repair.
Exhaust Manifold			Purchase part Outside Source.
Intake Manifold			10, 20, 30, 40, 50, 60, 70, 80.
Connecting Rod	10, 50.	20, 30, 40	
Connecting Rod Cap	40	10, 20, 30.	
Connecting Rod & Cap		50(2), 60(2)	
Connecting Rod Assembly	40(2), 80(4), Automatic Gage.	30(2)	10
Engine Assembly	All fixtures supporting engine on line conveyor		

TABLE 4-2. WINDSOR #2 - 255 CID RE-TOOLING (CONTINUED)

Operations	Re-Tool on site	Re-Tool at Vendor	Replace Complete all new
<u>Miscellaneous</u>			
Intake Manifold and Cylinder Head Foundry Repairs	Impreg-nator		Leak Tester(2), Impreg-nator.

relative to the output of each of the machining transfer line areas. This reduces significantly, the distances finished parts must travel to reach the block assembly area. Final engine assembly then begins at the center of one side of the plant and extends to an area at one end where additional space for expansion can be made available. Plant #2 uses the carousel method for final engine tests as opposed to Plant #1's individual test stands. Most of these differences are attributed to the fact that Plant #2 was laid out as an engine manufacturing operation at a later date than Plant #1.

The magnitude of an all new engine change obviously cannot be accommodated without production interruption. However, with proper planning and a majority of the tooling changes being accomplished at the vendor's facilities, the plant effectively will be closed down only four months. Ford's schedule for accomplishing this is as follows:

1. First an adequate back-log of inventory of the 351 engine in the 1978 model year will be created.

2. The material part depots supporting Plant #2 will close down in November 1978.

3. Engine support will end on December 22, with all machine lines down by the 23rd.

4. Removal of the old and installation of the new tooling then takes place immediately with a production launch curve starting about May 18, 1979.

5. Production rate will then accelerate in gradual steps from May through October 1979 when maximum peak load production capability is expected to be achieved.

The lead time for accomplishing this change, however, runs three to five years. The tooling industries supporting Ford in this endeavor started redesigning the manufacturing tooling 24 months ahead of installation. The total cost when all work is completed is quite high running anywhere from $150 million to $250 million.

These costs cover only those related to the engineering and facilities resident within Plant #2. The research and engineering costs attendant with redesigning the 255 block from the original 302 block would be over and above this amount.

4.3 REFERENCES

(1) Communication with F. Joseph Lamb Company - 7/25/78

(2) Communication with A. T. Cross Company - 7/31/78

(3) Communication with Buhr-Bendix

(4) Wall Street Journal - 1/27/78, p. 4
Detroit Free Press - 1/27/78, p. 8-B

Figure	Photo Credit
4-2(b) 4-4(b)	_Automotive Encyclopedia_, South Holland, IL.: Goodheart-Wilcox; 1977, p. 189, p. 192.
4-3, 4-8	T. Taylor, Corporate-Tech Planning Inc.

APPENDIX A

WINDSOR ENGINE PLANT #1

CYLINDER BLOCK TRANSFER LINE

OPERATION CENTER NO.	SUPPLIER	PROCESS	APPLICATION
10	Sunstrand	Mill-Broach	Locating lugs
20	Cincinnati	Broach	Banks, Bearing & Pan
30	Sunstrand	Drill-Chamfer & Ream Mill	Manufacturing Holes Bearing Sides
40	Ingersoll	Bore	Cylinders
50	Cincinnati		Front & Rear Face
60	Buhr	Drill-Chamfer Counter Bore Ream	Holes
70	Buhr	Drill-Chamfer Counter Bore Ream	All Holes
80	Buhr	Drill-Bore & Ream Drill & Chamfer Mill	Oil Holes, Side Cup Holes, Carrier & Holes, Drain Holes Manufacturing Pads
90	Buhr	Drill Ream, Drill & Chamfer & C Bore Mill	Holes, Manufacturing Pads
100	Buhr	Drill-Chamfer	Tappet Holes
110	Buhr	Tap, Probe & Blow-Out	All Holes
114R	--	Repair	Drill & Tapped Holes
120	Centri-Spray	Wash & Blow Off	Complete Block
125	--	Assemble	Main Bearing Caps
130	--	Torque	Main Bearing Bolts (10 Spindle NVT Runner)
140	Cross	Chamfer & Bore	Cam Bore & Crank Holes
		Ream	Dowel Holes
		Semi-Finish Bore	Distributor Shaft Hole
		Face & Chamfer	Thrust Bearings

WINDSOR ENGINE PLANT #1

CYLINDER BLOCK TRANSFER LINE (CONTINUED)

OPERATION CENTER NO.	SUPPLIER	PROCESS	APPLICATION
150	Cross	Bore	
160	Cincinnati	Fine Mill	
170	Ingersoll	Bore	
180	Ingersoll		
190	Micromatic	None	
200	Centri-Spray	Cleaning	
210	Apex	Plugging	
220	--	Test	
230	Shefield	Grader	
240	Ingersoll-Rand	Assy	Main Bearing Cap Tighten Bolts on Main Bearings.

WINDSOR ENGINE PLANT

PISTONS TRANSFER LINE

OPERATION CENTER NO.	SUPPLIER	PROCESS
10	--	Casting Qualification
20	LaSalle	Drill-Mill-Chamfer-Ream (8 Station)
25	LaSalle	Rough Bore
30	ACME-Grildy	Turning-Forming
35	--	Blow-off
40	LaSalle	Mill
50	LaSalle	Finish Bore (7 Station)
70	Immersion-Monorail	Tin Plating
80	LAMB	Bearing Inspection
90	--	Inspection
100	--	Repair

CONNECTING ROD CAP TRANSFER LINE

10	Detroit Broach	Broach
20	Detroit Broach	Broach-Chamfer
30	Matterson	Finish Grind
35	--	Deburr
40	Greenlee	Drill-Ream (5 Station)

CONNECTING RODS TRANSFER LINE

5	--	Forging Evaluation
10	Mattison	Rough Grind
20	Detroit Broach	Broach

WINDSOR ENGINE PLANT

CONNECTING RODS TRANSFER LINE (CONTINUED)

OPERATION CENTER NO.	SUPPLIER	PROCESS
40	Buhr	Drill-Ream-Chamfer (7 Station)
50	Mattison	Finish Grind
60	Greenlee	Drill & Ream (5 Station)
65	Lamb	Rough-Spot-Face
70	Kingsbury	Mill-Chamfer
90	Blakeslee	Wash

CYLINDER HEAD TRANSFER LINE

10	Cincinnati Broach	Broach
20	Lamb	Drill-Ream-Center Bore-Tap (83 Station)
30	LaPointe-Cincinnati Broach	Finish Broach (2 Lines)
40	Lamb	Drill-Finish Holes (15 Station)
50	Century Spray	Wash
55	--	Peaning
60	--	Inspection
65	--	Brush Holes
70	Sheffield	Inspection
80	Sheffield	Automatic Gauging
90	APEX	Assembly
100	Ekman	Assembly
110	Cimco	Assembly
120	Turner Bros.	Air Test (4 Station)
121	Tocco	Induction Hardening

WINDSOR ENGINE PLANT

CYLINDER HEAD TRANFER LINE (CONTINUED)

OPERATION CENTER NO.	SUPPLIER	PROCESS
123	--	Lab Check
125	--	Wash
126	--	Inspection

INTAKE MANIFOLD TRANSFER LINE

10	LaSalle	Machine Locating Lugs (25 Station Mill-Drill-Ream
20	LaSalle	Mill-Drill (33 Station)
30	LaSalle	Drill & Tap (17 Station)
40	Century Spray	Wash

EXHAUST MANIFOLD TRANSFER LINE (RIGHT & LEFT)

10	Lamb	Mill-Drill (26 Stations)
20	Lamb	Mill-Drill-Tap (21 Stations)
30	Century Spray	Wash

CAMSHAFT TRANSFER LINE

20	Kruker-Trunnion	Drill & Ream
11	Cincinnati Induction Holding Equipment	Induction Hardening
40	Snyder	Turning
70	Landis	Finish Grind
80	Norton	Finish Grind
90	Dake (Press)	Cam Straighten
100	Landis & Norton	Grinding

WINDSOR ENGINE PLANT

CAMSHAFT TRANSFER LINE (CONTINUED)

110	Cleveland Hobber	Hobb
--	--	Inspection
150	Monorail Co.	Wash & Dry
200	--	Coating
210	Impco	Lapping & Polish
230	Monorail Co.	Wash & Dry

CRANKSHAFT TRANSFER LINE

20	Producto	Mill-Center Drill
30	Wickes	Lathe-Chamfer-Turn & Space Filet
40	Wickes	Lathe-Finish
50	Kruger	Drill
60	--	Repair
70	Kruger	Drill & Counter Bore
80	Landis	Finish Grind
90	--	Repair
100	Landis & Norton	Finish Grind
110	--	--
120	--	--
130	Sunstrand	Finish Turn
140	--	--
150	Tinius-Olsen	Dynamic Balance
160	--	--
170	--	Manual Deburr

WINDSOR ENGINE PLANT

CRANKSHAFT TRANSFER LINE (CONTINUED)

OPERATION CENTER NO.	SUPPLIER	PROCESS
180	Impco	Polish
185	--	Repair
190	Impco	Brush & Flush Oil Holes
200	Hydromation	Wash & Blow
210	--	Manual Grading
220	--	Repair
230	--	Repair
240	--	Repair
250	Brakeslee	Final Wash

APPENDIX B

REPORT OF NEW TECHNOLOGY

After a thorough review of the work performed under this contract, no new innovations, discoveries, improvements or inventions were made or patents submitted.

The program did result in a better understanding of the automotive industry and its capacity to meet fuel economy goals as a result of the engine plant analysis and assessment of the effects of regulatory changes on the manufacturing process.

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